BEST PRACTICES IN COMMISSIONING IN THE STATE OF MONTANA

Montana Division of Architecture and Engineering
Helena, Montana

A report for the

Northwest Energy Efficiency Alliance

in cooperation with the

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NOTE for downloading from the Internet:

Download from the Montana DEQ commissioning web page.
Address is: **http://www.deq.state.mt.us/ppa/tfa/energy/buildings.htm**
Scroll down to Section II - "Resources and Links of Interest" and double click on the paper title to bring up the .pdf file. Requires Adobe Acrobat Reader to view, which is available free at www.adobe.com. The document prints out best on printers with at least 64 megs of RAM. If you have trouble printing, try printing a small group of 5-10 pages at a time.

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EXECUTIVE SUMMARY

Commissioning is a planned, collaborative and systematic process of review and testing conducted to confirm that a structure and its sub-systems perform as designed and as expected by the building occupants. In most cases this procedure takes place during the entire project, from planning and pre-design through final acceptance of the building.

Commissioning has been shown to improve building quality in hundreds of major projects nationwide and has been a successful addition to the Long Range Building Program for state-owned buildings in Montana. This paper describes the procedures that have worked best for the Architectural and Engineering Division in applying commissioning to new building projects.

A contracted consultant in private practice known as the Commissioning Authority (CA) typically conducts the commissioning process. This firm is chosen based on experience in a manner similar to consulting engineers and architects. The Division maintains a list of qualified commissioning firms that serves as the selection pool. The Division contracts directly with the CA firm to assure direct, open communications regarding building quality.

Other commissioning delivery methods exist. Commissioning services can be provided by construction contractors, by the architectural and engineering design team or by an in-house staff of commissioning specialists. The Division feels that having the A/E design team or the contractor checking their own work compromises the objectivity of the commissioning process. Further, we feel that placing the CA down the communications chain inhibits free and frank communication regarding building quality issues. This is consistent with the national consensus.

In awarding commissioning projects to CA firms, the Division looks for a staff including both professional engineers and experienced technicians. The Division also expects commissioning service providers to participate in the national commissioning community through conferences and continuing education and to be a part of national peer organizations. As a result of support for commissioning, Montana has seen the development of a number of commissioning service providers offering this specialized service.

We usually commission only the mechanical and electrical portions of new buildings. Independent third party commissioning is performed on new building projects with a construction cost of approximately $2.5 million or more. On smaller construction projects a simplified form of commissioning termed “streamlined commissioning” is used. This appears to give the best value for the dollar considering our climate and the types of buildings we construct. In other regions of the country a testing program for the building envelope and security is often a part of commissioning. Flexibility in commissioning different systems will provide the best value for the commissioning dollar.

In past projects the Division has negotiated fees of 1/2% to 1% of the new building construction cost as payment to the commissioning authority for the commissioning of mechanical and electrical systems. In other states, fees of about 1% have been paid for whole building commissioning including the building envelope and other architectural items. These fees are exclusive of travel, video taping, test-adjust balance (TAB) work and extra certifications beyond occupancy.

The body of the paper describes the commissioning process in sequential order through the course of a typical project. At the end of the paper is a list of references, most of which are described in the narrative. We highly recommend that any agency considering a commissioning program obtain these resources. Many are available over the Internet or from government agencies at no cost. Training courses offered at the annual National Commissioning Conference are also recommended.

The remaining sections include diagrams, spreadsheets, forms, lists and other documents. These help the reader understand the narrative and can be reproduced into visual aids for presentations.

Appendix 1 contains a list of policy guidelines that should be included in legislation regarding commissioning.

Introduction: What is This “Best Practices” Paper?

This document is a collection of the best practices developed by the Montana Architecture and Engineering Division (the Division) for the commissioning (Cx) of mechanical and electrical systems in new public sector buildings. The intent of this paper is to document and disseminate ideas and methods that will allow others to begin commissioning new buildings. Although developed in the course of commissioning public sector buildings, most of the procedures and tactics are applicable to private sector buildings as well.

The concepts herein were developed over the years of 1995 through 1999. The first draft of the paper was completed in January of 2000. The final version is the result of comments incorporated into the paper through May of 2000.

The practices described in this paper have been developed in the course of new building construction, new additions to existing buildings and extensive mechanical and electrical system building retrofits. The State of Montana does not currently commission other building systems such as windows, doors, exterior walls, roofs, vertical transportation equipment and voice, data and security systems.

Throughout this paper the attempt is made to differentiate opinion and experience from objective reference. In other words, if a procedure or practice has been documented and/or recommended by others, that reference will be listed. In the absence of a specific reference, it can be assumed that recommendations are based on (only) the Division’s experience.

What is Commissioning?

Simply stated, commissioning is the process of making sure a building works. A more complete definition is:

Commissioning is a planned, collaborative and systematic process of review and testing conducted to confirm that a structure and its sub-systems perform as designed and as expected by the building occupants.

Other definitions include:

<u>ASHRAE Guideline 1-1996, “The HVAC Commissioning Process”, 1996</u>:
The process of ensuring that systems are designed, installed, functionally tested and capable of being operated and maintained to perform in conformity with the design intent.

<u>USDOE Rebuild America, “Building Commissioning”, 1998</u>:
The process of ensuring that systems are designed, installed, functionally tested and capable of being operated and maintained according to the owner’s operational needs.

<u>USDOE, “Model Commissioning Plan & Guide Specs”, 1998</u>:
A systematic process of ensuring that building systems perform interactively according to the design intent and the owner’s operational needs.

Let’s take a closer look at this definition:

Commissioning is *planned*. This means that commissioning is a part of the project from the very start, ideally the programming or pre-design phase of the project. Furthermore, commissioning is *integrated* into the project. This means that commissioning takes place at every stage of the project: programming, design, construction and acceptance.

The factors of *planning* and *integration* are two key points that set commissioning apart from traditional construction quality assurance processes. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)[1], a leader in HVAC issues, offers a course that is very helpful in getting acquainted with commissioning quickly. The title of the course is “An Integrated Approach to Building Commissioning” and is indicative of the importance ASHRAE attaches to the integrated nature of this quality assurance process.

Early approaches to commissioning did not stress the integrated approach. One of the earliest advocates of the commissioning process is the National Institute of Standards and Technology of the US Department of Commerce. Their document “HVAC Functional Inspection and Testing Guide”[1] is a classic treatment of the technical side of testing HVAC systems. It goes into great detail about sensor accuracy, simulation of design conditions, sequences of operation and other electro-mechanical aspects of testing. This document is available for little or no charge from NIST and is a valuable addition to the commissioning reference library.

Planned and Integrated Commissioning is Vital

The Division has found that the planning and integrating of commissioning is important for several reasons:

- *Planning commissioning from the programming stage introduces all members of the design and construction teams to the process early. This avoids exposing team members to unexpected reviews and service requirements during the course of the project.*

- *The Commissioning Authority (CA) should confirm that the Design Intent is complete during the programming phase. The design intent document is described in more detail later in this paper.*

- *The CA checks the construction plans and documents during design to confirm that the design includes provisions for testing and confirming correct operation.*

- *The CA writes "Division 17" (and/or other sections) of the specifications that describes contractor duties related to commissioning.*

- *The CA presence at pre-bid and pre-construction conferences further acquaints contractor personnel with the commissioning process and draws the contractor(s) into the project team.*

Commissioning is Collaborative, Systematic and Documented

Commissioning is *collaborative*. It is a team process from the very beginning. *The most important responsibility of the CA is team formation.* The experienced commissioning professional causes quality to be built into the project from start to finish by creating a heightened respect for quality within the team. To be sure, there is a certain amount of error identification, both in design and construction. But in the main, quality is built in, not added on.

Commissioning is *systematic*. Commissioning includes testing all items in all modes of operation. Equipment is first inspected in a static condition to assure it is installed correctly. Moving equipment is then started up (and electrical equipment energized) for the first time under controlled conditions. After equipment is started up, systems of equipment are tested running together to prove that the system as a whole will operate as required.

Systematic refers to the commissioning building blocks of inspection, start-up and testing. It also refers to the "systems" nature of modern buildings. The commissioning process is organized by system (i.e.: air handling units, pumps, boilers, chillers, water treatment, fire alarms, smoke evacuation, door locks, roofs, walls). Grouping the building into sub-systems makes it easier to understand how the building works and provides a framework for commissioning.

Commissioning is *documented.* The value of commissioning remains long after the building is accepted and turned over to the operating staff. In the course of commissioning, key parameters of the systems are documented, organized and preserved in the commissioning report. Not the least of these items is the design intent. The commissioning report records the intended use of the building and its various spaces so that if personnel change, operating staff will be able to understand why things work the way they do.

The review and approval of the Operations and Maintenance (O&M) manual and the organization of the training program are also frequently assigned to the CA. This further insures that the tools required for future correct building operation are provided for the staff by the completion of the project.

Why Commission?

The main benefits of commissioning are:

- *The assurance of a correctly operating building at completion; and*
- *Setting the stage for continued correct operation through training and documentation.*

To better understand these benefits, consider the increase in the complexity of building components over the past three decades (see *Figure 1* - Appendix 2). There has been a greater increase in the complexity of building components in the last thirty years than in the 200 years before. Thirty years ago buildings operated by microprocessors were a novelty. Now nearly all buildings are operated by a building automation system (BAS) and large institutional buildings have dozens of microprocessors. The same goes for automatic valves, actuators, solid state sensors, occupancy sensors, CO_2 sensors, variable frequency drives, pure water systems, fume hoods, biological hoods and other modern appurtenances.

Consider the increasing use of technology to meet the demands of safety and efficiency. The energy crisis of the 1970s brought about a huge increase in America's energy consciousness. This is reflected today in building codes as well as design standards. Buildings must operate at a higher level of efficiency than they did thirty years ago. They attain this level of efficiency largely through the use of the sophisticated components described above coupled with complex computerized building operating strategies.

Consider the increase in the use of new materials over the past two decades. New materials have been incorporated into wall finishes, insulation, carpet, ceiling tiles, window coverings, office equipment, furniture, paper, books, cleaning agents and almost every other item to be found in the modern workplace. All these items cost less and provide better service. Unfortunately, many of them contain untested chemicals that deteriorate the building air quality and cause allergic reactions for some workers unless a building's HVAC systems are operating correctly.

New mechanical and electrical components, sophisticated operating strategies and new building materials have kept building construction and operating costs down. But this has had a subtle effect on funding for design. Specifically, architectural and engineering design fees have stayed at a constant percentage of construction costs, while building complexity has increased several times over. This has caused engineering design firms to distribute a fixed design fee among more design details and, as a result, spend less time on any one detail. This has resulted in engineers allowing more of their design work to be in the form of standard designs provided by vendors and contractors. The result is that vendors and contractors may have more information on hand about design details than the engineers do.

Although this works fine in many cases, vendors do not have the same fiduciary responsibility to the owner that consultants have. They sell their products on the basis of "low bid", not customer satisfaction. The end result is that complexity, originally intended to benefit the owner, has also placed more responsibility for quality assurance on the shoulders of the owner.

Commissioning for Maintenance

In the same way that engineering fees have remained relatively fixed, funding for maintenance and operations has stayed about the same on a unitary (per square foot) basis. This funding fails to reflect the increased complexity of the building and the education and ongoing re-training required for the operations and maintenance (O&M) staff.

The result is an ever-widening gap between what the contractor installs and what the operating staff is ready to accept. System components can be correctly sized, specified and supplied, but not installed, adjusted and integrated to work optimally on the job. The consequence is that the uncommissioned building doesn't work correctly when it is built and the operating staff doesn't have the time to figure out why. In fact, the operations staff may be unaware that the building is operating incorrectly until the occupants complain. At this point, the productivity of the occupants has been reduced and they have been sensitized to the poor building environment.

This results in an *operations death spiral* in which the building staff is spending all their time attacking the symptoms of installation and design problems and has no training or time to attack the root causes. This is evidenced by the bypassing and disconnection of automatic controls and other equipment that has not been tested and adjusted to work smoothly as part the overall installation. The result is steadily deteriorating environmental quality in the workspace, reduced energy efficiency and building performance that falls short of the owner's expectations.

The cost of these consequences is huge. The total adds up to many times the cost of commissioning.

Commissioning is the Total Quality Management process applied to building construction. It builds quality into the project and confirms correct operation through testing. Quantitative and qualitative data supporting the benefits of commissioning is available in quantities beyond the scope of this paper. One of the best resources for a concise listing of commissioning benefits is the booklet "What Can Commissioning Do For Your Buildings" by Portland Energy Conservation, Inc. (PECI[2]). This brief brochure is about twelve pages long and is available in quantities. It is a valuable addition to any program promoting the benefits of commissioning.

Commissioning Delivery Methods

There are several variations in the way the commissioning process can be applied. It can be coordinated by a CA who is:

- *An **independent service provider** under contract to the owner;*
- *Part of the owner's **in-house** commissioning staff;*
- *Subcontracted to the **architect** as part of the design team; or*
- *Subcontracted to the **contractor** as part of the contractor's team.*

Also, the contractor may or may not employ a Test Engineer (TE) to develop and execute Functional Performance Tests (FPTs) which are developed by the CA. Balancing may or may not be included in the commissioning contract. Commissioning may include the building envelope, the building HVAC systems, controls, electrical, security or any combination of these systems.

With few exceptions, the Division recommends using an independent third party CA under contract directly to the owner. The CA is contracted to write commissioning specifications and to develop and oversee acceptance tests which are performed by contractor personnel. Balancing is not included in the commissioning contract and is left in the contractor's scope of work in the usual manner. The author believes that the use of an in-house (staff) CA would offer a slight improvement over the consultant, but the creation of a commissioning staff is not yet feasible for the Division. There is not the quantity of work to justify such a staff. Nor is such a staff feasible for many small public sector agencies.

The use of an independent third party or staff CA is the most recommended delivery method nationwide. The ASHRAE course cited above, for example, is based on the use of this method and is itself based on the ASHRAE commissioning guideline[3] that has adopted this method. It provides an independent champion for quality with the minimum possible conflicts of interest. Communication with the owner is direct and fiduciary. The Association of Higher Education Facilities Officers Handbook[4] also advocates the use of the independent third party CA.

Figure 2 (Appendix 2) outlines the major benefits and drawbacks of different delivery methods. Although the independent third party option may cost the most (in "out-of-pocket" dollars), it is the only option that provides direct accountability to the owner. Based on the Division's experience, the main difficulty in using the third party CA is that the individual doing the work needs to have considerable talent and skill in fitting in with the project team. In other words, just as the "outsider" nature of the CA helps his impartiality and allegiance to the owner, this same outsider nature makes the design consultants and contractor team suspicious of the CA and lacking in respect for the CA's abilities. The emerging nature of the commissioning process may aggravate both these factors. Owner involvement is critical to the assurance of success.

The use of a CA sub-contracting to the design architect is the next most accountable option in that the architect has a fiduciary relationship to the owner. That is, the architect is legally bound to act in the owner's best interests. This option has the advantage of one less contract for the owner to manage (although the architect may charge for this service with a mark-up). The disadvantage is that the CA's communication goes through the architect, who is arguably the least qualified member of the design team to evaluate difficult electro-mechanical system issues. Although the Division has had success with this method, we demanded direct communication with the CA, bypassing the architect. In the end, our experience was that the CA would rather have worked directly for the Division.

A CA employed by an on-site, owner-contracted CM is a promising option that the Division has not yet employed. The Division would still require direct communication with the CA to provide the most positive acknowledgement of problems and the most direct corrective action. We have had good results with placing some commissioning responsibilities in the hands of the on-site construction manager. On large projects the CM is on the site every day dealing with a myriad of issues and the occasional inspection or test seems to fit in. This is especially the case in the early stages of static inspection including pipe and duct pressure testing and equipment installation.

Placing commissioning under the supervision of the CM creates a timing problem in that the CM may not be hired until the construction plans are complete. If the CA firm is not hired until this time they will not be able to review the construction drawings prior to bidding. In the case of design-build projects and “CM at risk” projects, the CM is contracted prior to design and therefore will be able to sub-contract to the CA in time for plan review.

If the CA is a sub-contractor to the general contractor or to another sub-contractor, it appears to this author that the responsibility placed on the shoulders of the owner’s staff is so great that the staff may as well commission the job themselves. This method is not recommended by most commissioning organizations. However, it is used by one the pioneering commissioning organizations, Montgomery County, Maryland[5].

Several other references provide good sources of additional information on contrasting commissioning delivery methods. Paul Tseng’s Montgomery County Maryland guideline[5] contains some very good discussions on different delivery methods. They require the general contractor to hire and manage the CA and the commissioning process. The Oregon Energy Office commissioning booklet[6] also reviews different delivery methods.

When to Commission?

No doubt some advocates of commissioning would say, “Always!” No doubt some others would say, “Never!” Regardless of varying opinions there exists the practical necessity of setting parameters for deciding which projects are appropriate for full-blown third party commissioning. There are some projects that are too small. In these projects the administrative overhead of a separate contract may outweigh the consequences of an extended trouble-shooting period. The Division’s (developing) policy is to perform independent third party commissioning on new building projects costing about $2,500,000 or more. Commissioning is also performed on mechanical system retrofits costing about $800,000 or more.

On projects smaller than this, the Division requires commissioning by the design team (“streamlined” commissioning). This type of commissioning results in a commissioning report and documentation that is monitored by the Division in the same manner as if the project were third party commissioned. The Division believes that streamlined commissioning can be done for less, but that the “in-house” (by the consultant) nature of the work makes it less rigorous than third party commissioning.

Note that the use of the design team as the CA assumes that they have the staff, equipment and experience to do commissioning work properly. An excellent design firm may not be organized to provide commissioning services and may not be interested in committing to doing so. If that is the case, the owner must look elsewhere for such services. The decision to perform streamlined commissioning is made by the Division prior to negotiating the design contract with the design team. This allows the design team to voice objections and/or the Division to select a different firm if the services are not acceptable to either party.

Larger but less complicated buildings also appear to benefit from streamlined commissioning. Projects that employ simple or repetitive building systems are candidates for streamlined commissioning even though their construction cost runs to $2.5 to $3.0 million. Office buildings and elementary schools are examples of buildings that typically employ less complicated mechanical and electrical systems. Research labs and hospitals would be more likely to receive third party commissioning because of their complexity. Of course, it is likely that most research labs would cost more than $2.5 million and so would be third-party commissioned based on cost anyway.

The application of streamlined commissioning for these projects does not mean they don’t have to work right! Completely correct operation is every bit as critical for a school or office building as it is for a laboratory. A final commissioning report is required for the streamlined project and is held to the same standards of quality as the third party commissioned project. Documentation and training should be complete and appropriate for the level of complexity involved.

The US Army Corps of Engineers[8] includes a factor called “Significant Consequential Magnitude” in their decision making process. This reflects the importance of commissioning a building when failures in the building could have serious effects, such as life-threatening consequences. An example of such a building might be a biological or medical containment structure.

Most agencies have higher dollar limits than the Division in establishing the requirement to commission, because their projects are bigger. For instance, the guideline for the State of Washington, Engineering and Architectural Services Division is $5 million total or $2.5 million for renovation projects (as of August 1995). The Army Corps of Engineers lists $10 million for new projects and $5 million for renovations (see reference below).

Regardless of whether integrated third party commissioning or streamlined commissioning is used, the owner must have involvement. It is only through the owner's understanding and monitoring of the quality assurance process that true quality is achieved. A very good paper on streamlined commissioning has been written by Stum and Haasl and is available through PECI in Portland, Oregon[7].

Selecting the Third Party Independent CA

The Division selects CAs for our public sector construction projects in the same way we select consulting architects and engineers[2]. The CA is selected based on qualifications, not through a bid process. We believe that the service the CA provides is a professional service, not a commodity, and therefore not amenable to the “low bid” process.

The Division has created a file of information on firms offering commissioning services. Any company that wishes to be considered for commissioning projects is required to send information on qualifications that is included in the file for future reference. A firm is allowed to submit qualifications and be placed on the list at any time. Although the Division has not yet created a list of hard and fast requirements, we have told potential commissioning firms that we expect to see the following general strengths in the firms that work for us:

- *A registered professional engineer on the staff who will be directly involved in commissioning activities;*
- *An experienced control technician or test and balance technician on staff;*
- *Experience in field engineering such as remote monitoring or the field trouble-shooting of HVAC systems or energy conservation retrofits and programs;*
- *Involvement in the national commissioning community as evidenced by attendance at the annual National Conference on Building Commissioning, membership in the Building Commissioning Association or other similar activities; and*
- *Continuing education in commissioning consisting of staff attendance at seminars and other training sessions.*

As commissioning projects are started, the file is consulted and a list of three firms is created for submission to the Director of Administration. If the Division anticipates a CA fee of over $250,000, the three firms must be invited to interview for the project and a uniform written scoring process must be followed. As our highest CA cost to date has been under $150,000 it is not likely that the Division will be interviewing for CA services in the near future.

The three selected commissioning firms are chosen as best qualified for the following reasons:

- *They have the expertise and experience required for the level of complexity represented by the project;*
- *They are in reasonably close proximity to the project (the same city is best, but usually not possible in Montana); and*
- *They have the staff size to be able to handle the size of project proposed.*

For the Division, the establishment of the selection list is managed by the Division's design project manager (PM). The list is *created jointly* with a representative of the project agency, such as the agency's facility coordinator or maintenance manager. After this list is created, it is further reviewed with the lead architect and engineer of the design team. Although the design team does not have the right to veto firms selected for the list, they are given the chance to state objections based on conflicts of interest, past bad experiences, etc. These objections are then researched by the Division project manager who makes the final decision as to whether the firm in question remains on the shortlist.

Finally, the list of three firms is forwarded to the Director of Administration for the final selection of one firm. After a firm is selected, the Division negotiates a fee with that firm based on the scope of work defined in the owner's Commissioning Procedure. The commissioning procedure is written by the PM and reviewed by the design team and the customer agency prior to the CA selection process. If a mutually acceptable fee cannot be negotiated, another firm on the original list of three is selected and negotiations repeated.

This has been adopted as the CA selection procedure by the policy in Appendix 3: "State of Montana Commissioning Authority Selection Procedures". The Association of Higher Education Facilities Officers "Building Commissioning Handbook"[4] has additional material on evaluating and selecting the CA.

The Building Commissioning Association

The Building Commissioning Association (BCA) was formed in the late 1990s as an association of independent commissioning service providers. Originally named the *Northwest* Building Commissioning Association, the BCA recently expanded its scope to the national level and dropped the "northwest" limitation. The BCA has adopted a stringent list of qualifications to be met by firms wishing to become commissioning service providers and have adopted a peer review system similar to the National Environmental Balancing Bureau (NEBB) and the American Air Balance Council (AABC) to further assure customers of a reliable service. The creation of this organization is an important step in providing a uniform, reliable market of service providers. Although not a comprehensive source, the BCA is a good place to start identifying potential commissioning authorities[3].

Other Selection Procedures

If the commissioning is to be done by the consulting design team, that team would also be selected based on qualifications as presented through interviews. Therefore, the selection process is essentially the same whether the CA is a third party or a sub-consultant to the design team. If the latter is the case, the CA should make the commissioning presentation as part of the design consultant's presentation and the team should be selected as a unit. The design consultant should *not* be allowed to switch CAs after they have been selected for the project.

After the selection, the consultant team's fee is negotiated as described above. The CA fee should be a line item in the overall fee and should be negotiated apart from conventional design fees.

If the construction manager (CM) employs the CA, the CA should be part of the CM team from the very beginning. The CM/CA team should be selected as a unit with no substitutions allowed after the selection. The Division also selects CMs based on qualifications and follows that selection with a fee negotiation based on accepted fee guidelines.

If the CA is part of the contractor's team, the owner loses most control over the selection of the CA. It is possible in Montana for the Division to negotiate a CA fee with a commissioning firm before the bid process and require that all bidding contractors use this firm at the specified price. However, this exposes the project team to conflicts between the contractor and the CA with attendant negative effects on quality. Overall, we feel that the loss of communication and impartiality that results when the CA works for the contractor makes this arrangement undesirable.

Defining the Scope of Work—The Owner's Commissioning Procedure

In the Division's projects to date, the owner's commissioning procedure has been written by the owner's project manager (PM) during the early stages of design or during pre-design programming. This document forms the basis of the scope of the commissioning work and is the forerunner of the *Preliminary Commissioning Plan* that is included in Division 17 of the bid specifications and the *Commissioning Plan* that is released during construction (see *Figure 6* of Appendix 6).

If the CA were selected during pre-design, they could write this document. However, the Division has not yet succeeded in making the selection early enough for this to occur. Regardless of the benefits either way, having the owner's PM fill the shoes of the CA during pre-design has the advantage of insuring owner involvement during this critical early stage. In either event, the CA uses the commissioning procedure to develop the preliminary commissioning plan that is included in Division 17 of the specifications.

The Division has been developing a commissioning procedure for projects for about the last four years. The current result of that process is shown in Appendix 4 where the commissioning procedure for the State Capitol Renovation is included as an example.

The document begins with an overview and then names the commissioning team. Being clear on the team is important for several reasons. The main reason is that team formation is probably the most important part of the CA's job, who needs to know the team members from the start. In a small (population) state like Montana, everybody has a history. In a larger state this might not be as much of an issue.

The systems listing is the heart of the document. This is where the owner's project manager is on the spot in judging what portions of the building are most vital and will return the greatest benefits from commissioning . The Division includes all HVAC, most plumbing, all major equipment, the Energy Management and Control System (EMCS), variable frequency drives (VFDs) fire alarm interlocks, training and O&M manual review. Items that should be included when they are present include fume hoods, biological hoods, pure water and lab gas systems and security systems.

In most of the Division's projects, items such as elevators, power assisted doors and specialty systems such as closed circuit television are optional. For remodeling projects existing piping and equipment is also optional. Certification for special government programs and energy conservation retrofits may also be included as part of the CA's work.

The commissioning procedure describes the commissioning responsibilities by construction phase. This section will vary depending on when the CA is brought into the project. In the sample project the CA was brought on board after design so they were not a part of planning and design. In a better example the CA reviews the construction documents during design and confirms the design intent document. Those activities will be described in more detail below.

The Commissioning Service Provider's Proposal

The Division commissions new building mechanical and electrical systems. We do not do "whole building" commissioning that could include the building walls, doors, windows, roof and other items. So the fees discussed herein are for new buildings where only the mechanical and electrical systems are commissioned. This is not to say that the CA cannot be requested to look at these items, but such services might increase the costs indicated in the guidelines described below.

The database below will help the reader gain a perspective on commissioning fees for projects across the nation. These costs are taken from new building commissioning projects including mechanical and electrical systems and were documented with detailed, system by system, proposals from the commissioning service provider. Although these costs correspond roughly to a model of 2.5% of mechanical costs and 1.5% of electrical costs, actual fees vary. For this reason the reader is cautioned that actual CA fees can only be established through a complete understanding of the project and an analysis of the project on a system by system basis.

After the commissioning procedure in Appendix 4 is the Commissioning Services Fee Estimation and Proposal Worksheet. This is the form the Division gives to commissioning service providers to assist them in providing the level of detail we require with their fee proposal. Several firms have expanded this worksheet into a labor matrix with an attached summary. A sample of a labor matrix for the fee proposal for the University of Montana Pharm/Psych building follows the proposal worksheet. Following the matrix is the Commissioning Cost Summary. The summary sheet collects the totals from the matrix sheets and presents them with a grand total.

The labor matrix and summary show the level of detail the Division expects in proposals for our projects. The left-hand column lists the systems to be commissioned. This list is taken directly from the condensed list included in the owner's commissioning procedure. Subsequent columns to the right include labor hours for each stage of the commissioning process.

The last item in Appendix 4 is the Commissioning Services Request for Payment. Contract amounts are listed in the left-hand column. As the project proceeds, percentage amounts of completion are filled into the center column and the corresponding dollar amounts calculated in the right hand column. The right hand column amounts are totaled down with extra services added. Finally, the total of all previous payments is subtracted and the net due appears on the bottom line.

This form works well in that it shows the progress of the commissioning month-by-month. The owner's PM can see the percentage complete figures increasing through the design, bidding, pre-construction, construction and acceptance stages. The Division typically retains 5% to 10% of the fee earned to assure the CA's completion of the project, but withholding this retainage at the end of the project to force completion has never been required. The Division withholds the same amount for consulting services.

A proposal in using the labor matrix assures that the CA has thought the job through and allows the owner's project manager to check the proposal for completeness. The goal is to head off misunderstandings at the earliest possible stage. The phases in the fee estimation worksheet correspond to phases on the billing form (discussed below). The proposal becomes part of the accounts payable file for the CA. This allows the project manager to monitor the progress of the CA as the job proceeds and approve pay requests according to the amounts specified in the original proposal.

Before the CA has submitted the proposal the owner' project manager should have studied the commissioning project and prepared a cost estimate. In fact, the PM should have prepared the commissioning cost estimate one to two years earlier so it could be included as part of the project planning.

Commissioning Fee Guidelines

The first page in Appendix 5, entitled “Pine Hills Juvenile Correction Facility Budget” shows a sample spreadsheet for an early estimation of a commissioning budget. The spreadsheet breaks out the cost of the mechanical and electrical work and applies factors to estimate the commissioning fee. In this case the factor was 2% of the HVAC and Fire Alarm costs and 2% of ½ of the plumbing costs. The lower weighting of the plumbing costs indicate commissioning plumbing only for leak tests, flushing and sanitization.

The next two pages in Appendix 5, entitled “Costs of Commissioning New Construction” list some typical guidelines for commissioning work and their associated references. If there is one thing to be learned from this information, it is that the numbers vary. The guidelines are starting points only. However, when an agency is beginning a commissioning program, it must start somewhere and learn with experience.

The Construction Cost Model

Based on detailed proposals for CA services, the costs in *Figure 3* of Appendix 5 have been collected from projects in the states of Montana, Washington and Missouri. These amounts were tabulated from proposals detailed down to line items on a system-by-system basis. Projects numbered one through four were early projects and are not representative of standard commissioning processes. These were projects that included partial commissioning of HVAC systems, focusing on energy efficiency items or problem areas. The remaining 15 cases may be considered in three groups:

- *Projects 5 through 12 are representative of a standardized commissioning process for Montana projects in which the CA is an independent third party retained during the design process (in the future, the Montana A/E Division will be retaining CAs prior to design). For these projects, CA costs vary from a low of 1.5% of combined mechanical and electrical to a high of 3.8%, with the average being 2.4%.*

- *Projects 13 through 17 (projects in the State of Missouri) consist of four large prison complexes and one research laboratory. These projects are more expensive than, but similar in average complexity to, the group described above. For these projects, CA costs vary from a low of 1.6% of combined mechanical and electrical construction cost to a high of 2.8%, with the average being 2.3%.*

- *Projects 18 and 19 (projects in the State of Washington) are of a similar size and complexity to the first group. The higher percentage CA cost is 2.6% of mechanical and electrical and lower is 2.3%. The average of 2.45% is virtually the same as the previous two groups.*

Based on the reference guidelines, these costs indicate that the documented experiences of Montana, Missouri and Washington appear to be typical of North American averages. However, at the same time it should be noted that the reference guidelines span ranges of over 300%, bearing testimony to the developing nature of the commissioning process.

Figure 4 shows the same list of projects broken down into mechanical and electrical construction costs. “Model” CA costs were then calculated based on an arbitrary 2.5% mechanical and 1.5% electrical guideline and compared to the actual CA fees. The right-hand column then summarizes the variation from the model in percent over or under.

In general, projects 5 through 12 have a good correlation with the arbitrary guideline. Projects 7 and 11 have higher than expected commissioning costs due, in part, to high travel costs. Project 7 employed a CA from out of state and the project 11 CA incurred approximately 350 miles for each round trip to the construction site. Each CA included approximately $20,000 to $30,000 in the overall fee for travel.

Incidentally, this author recommends evaluating basic commissioning cost apart from extras such as travel, videotaping, code reviews and test and balance. Although it may be cost-effective to include some or all of these items in the CA’s scope, their inclusion in the commissioning cost needlessly complicates the analysis. Extra services are more easily evaluated separately.

If travel and video-taping are removed from these fees, all eight projects fall into a range of ± 33% of the “2.5%/1.5%” model (incidentally, the two projects with the lowest comparative costs (projects 6 and 12) employed CAs which were either in the same city or a short driving distance away). A variation of plus or minus one-third still leaves the sample costs well within all of the guidelines listed above.

The remainder of the projects (nos. 13 through 19) are also within a range of plus or minus one-third of the model predictions.

The Square Footage Model

Utilizing building square footage to model commissioning costs appears more complicated than using construction costs. This is due to complexity factors that are inherently included in system cost but are not included in the size of a building’s floor area.

Figure 5 lists unitary CA costs for the sample buildings. Buildings numbered 1 through 5 and number 8 were only partially commissioned and therefore are not included in the analysis. Building 8 is included in the construction cost analysis above because the complete mechanical system was replaced. Excluding these buildings, the remaining six Montana buildings show commissioning costs varying from $0.54/sf to $1.40/sf.

The highest example, “mental hospital” number 11, incurred high travel costs as described above. Without travel costs it would be closer to $1.15/sf.

Of the six buildings, the office is the lowest cost example, at $0.54/sf. The three lab/classroom buildings and the correctional center are next higher at from $0.79/sf to $1.11/sf. The mental hospital is the highest at $1.40/sf. Although this is a very small sample of these case histories, the trend shows that cost per unit of floor area does tend to increase with complexity and is in the general range of $0.50 to $1.50/sf.

For the Missouri prisons CA costs ranged from $1.31/sf to $1.02/sf. This places them above the cost of the Montana office buildings and slightly above the cost of the Montana lab/classroom and correctional facility (a juvenile facility). The Missouri laboratory is very high in cost, reflecting a high level of complexity.

The Washington Student Union building is more expensive than the Montana offices and classrooms and less than the hospitals and prisons. The hospital is about the same as Montana's mental hospital, slightly above the average prison, but still well below the research lab.

<u>But consider this perspective</u>: for one particular project on this list, incidental research revealed an actual range of commissioning fee proposals of <u>$0.50 to $2.50/sf</u>! Let the buyer beware: *the field is young and opinions on costs vary considerably*!

To Summarize CA Cost Data:

- *Most projects appear to follow an approximate cost guideline of 2.5% of mechanical and 1.5% of electrical construction cost, within a range of plus or minus one-third.*

- *Most projects appear to have commissioning costs in the range of $0.50 to $1.50/sf, with classroom and office buildings in the lower one-third of the range, lab/classrooms and correctional facilities in the middle third and hospitals and research labs in the upper third.*

- *CA costs appear to contribute most of the cost of commissioning, ranging from 66% to 88% of the total.*

These costs do not include travel, videotaping, code reviews or testing and balancing, which are sometimes added to the CA's scope of work. Furthermore, they do not include the commissioning of special systems such as prison security systems or audio/video systems.

Both the floor area and construction cost guidelines appear to point to approximately the same cost for the commissioning authority. However, one method may be more applicable than the other depending on the type of project. For instance, if only part of a new facility is being commissioned, the use of the floor area guideline might work best. If an existing building is being retrofitted with an entirely new HVAC system, the construction cost guideline appears to be the most applicable.

Regardless of the estimation method used, pricing and negotiating the actual commissioning services should only be done with reference to a detailed listing of systems to be commissioned.

The Commissioning Process Step-by-Step:

A comprehensive view of the commissioning process can be considered to have eight distinct sub-sections. They are as follows:

- *Pre-design/Planning*
- *Design*
- *Bidding*
- *Early Construction*
- *Acceptance-Static Inspection and Start-up*
- *Acceptance-Functional Testing*
- *O&M Staff Training and Documentation*
- *Post-Acceptance Testing, Verification and Training*

The Commissioning Process—Pre-design/Planning

The most important components of this early phase of the project are the Design Intent (DI) and the Basis of Design documents.

The DI is the occupants' *intention* of the *design*. Correspondingly, it is their assumed operation of the building. It is their expectations for the building. In order for the project to be successful, these expectations of operation must form the goals of the project team. The components and systems tested must perform *as required by the building occupants* (or owner) in order for the overall building to be considered as operating correctly.

As the criterion for correct building operation, the DI may include only HVAC, fire suppression or other systems. Or it may include a description of correct operation for everything in the building from power quality to cabinet latches. The DI is complete in its scope and verifiable in its requirements.

Regardless of what the document includes it is architectural in origin and should be developed, assembled and organized by the project architect. The document is performance based and concentrates on what the occupants *need* rather than on how the design team will provide it.

This does not mean that architectural considerations are foremost in the document. If only mechanical and electrical systems are being commissioned then a sufficient DI may be 90% those disciplines and 10% architectural issues such as building code requirements, occupancy, etc. Even so, the document is best prepared by the architect. The architect is the design team member who has the primary responsibility to translate the owner's needs into building components such as occupancy type, room size, population, air quality, etc.

The engineers start with these translated needs and specify systems and approaches which will meet the needs based on standard applications and vendor information. This is, essentially, the *basis of design*. The engineers then proceed to quantify the basis of design in producing the actual bid documents.

The job of the CA is to assure that components have been supplied and installed correctly according to the bid documents, and also to also assure that the occupant's needs are met as described in the DI. Therefore, the CA needs both the DI, based on the architect's knowledge of the occupants' needs, and the design itself that shows the specified solution.

The DI should not be kept a secret during the construction process. The design team at the pre-bid conference should present it and solicit ideas from the contractor. It is true that the contractor will build according to the plans and will expect change orders for any work not shown on the plans. It is also true that some contractors will count on making money from such change orders and so will not tend to suggest improvements prior to bidding. However, some contractors may make such suggestions prior to bidding if they are given a chance to see the actual intent of the structure. If they are given only the design, and not the intent, they can not be expected to help improve the project without change orders.

The document should be presented again at the pre-construction conference. The presentation of the design document at the pre-bid and pre-construction conferences should be used as a team building tool in defining a common goal. This is where the communication and team building skills of the CA are very important.

When the DI is presented to the construction team, it should be accompanied by the basis of design. The basis of design explains how certain systems and space arrangements were chosen by the design team to meet the needs of the occupants.

The most basic inclusion in the DI is the general description of the building type. For example, prison, hospital, classroom, geriatric, office, etc. Beyond the building type, details are stated such as the occupant's age group, particular needs with regard to air purity, outside air volume, occupant load and pattern of occupancy.

For example, the DI might describe an assembly area which is to contain one hundred persons for two hours, be empty for an hour after that and which is to provide comfort and operate at maximum energy efficiency. The basis of design could specify a variable air volume system integrated with occupancy sensors and special programming and the actual design in the bid documents could specify components, air volumes and the required control sequence. Commissioning would assure that the equipment has been supplied and installed correctly, the air volumes and control sequence are correct and that the overall system "works" at each occupancy level.

According to the current procedure employed by the Division, the DI is used by the Owner's PM to construct the commissioning procedure. The basis of design could be used as well, but it may or may not be available during the pre-design stage depending on when the design team is selected.

Appendix 6 begins with a summary of the elements that should be included in the Design Intent document. Following this summary is an example of a DI narrative used on a lab project at Montana State University. This DI document includes more technical detail than is necessary at this stage, details that should be included in the basis of design document instead. Nonetheless, this example does an excellent job of reviewing each space and describing in detail how each space is to function.

After the sample DI there is a summary of the elements of the Basis of Design. The basis of design describes the actual technical approach planned for the project as well as the actual design parameters to be used.

The last item in this appendix is the *Figure 6* that shows how the DI narrative is the forerunner of the commissioning plans.

The Commissioning Process—The Design Stage

The CA continues to "build in" quality during the design stage by checking the design documents. This checking should be coordinated by the owner's PM and takes place at the same time as the other owner reviews. However, the Division restricts this checking to a small part of the overall design . Our checking is specific to confirming that the documents:

- *Are consistent with the design intent,*
- *Include inspection and testing details,*
- *Include equipment parameters that can be verified,*
- *Incorporate a layout that allows testing and maintenance, and*
- *Fully describe the commissioning process for the bidders.*

The Division does not require or encourage the CA to check the design for engineering approach, system selection, equipment specification, energy efficiency, life cycle costs or other parts of the overall engineering design. The staff mechanical plans checker does that. The goal of the CA's checking is to assure that the system can be verified as working correctly and that the system can be maintained in that condition.

The goal of these groundrules is to prevent the CA from "second guessing" the design engineer. The owner trusts the design engineer or they should not have hired the engineer in the first place. If the owner wants the design engineer to look at alternative solutions the owner should require that, not seek alternative solutions somewhere else. There are always several ways to solve any engineering problem and the CA does not usually have the time, nor is he paid to, design alternative solutions. This may only muddy the water and breed ill feelings in the project team. This practice borders on the unethical if the CA is a design engineer who may be competing with the project design engineer in the future.

Nonetheless, the CA is responsible to confirm that the design at hand will handle the environmental requirements of the building. If the CA thinks it may not, they describe why they came to that conclusion and let the design engineer respond. It is important that the owner's PM moderate this process. It is also important that the PM have the engineering skills to understand the issues involved. If the owner does not exercise these skills, the CA checking process can break down into acrimony. Another reminder that owner involvement is a necessary part of commissioning.

Other organizations do this differently and give the CA a broader scope in performing the design review. This may be effective if the owner's PM has sufficient technical skills to evaluate an alternative design and manage the process of taking the best parts of both designs for a final design. There would also be less acrimony in this situation if the CA and design engineer were part of an engineering community large enough that they rarely competed against one another. Given the small population of Montana, ongoing competition makes impartiality problematic.

The other part of the checking process is confirming that each piece of equipment, piping or system is capable of being tested and has objective performance parameters which can be confirmed. An example would be to confirm that pumps and other hydronic devices have test ports across them to allow flow measurement. Another example would be to check for maintenance access to air handling units and straight duct lengths where air flow measurements can be taken. If a dual pump operating sequence is unclear, it will not be possible to verify its correct operation. This is another item the CA should flag.

Writing the Specifications

Along with checking the documents, the Division requires the CA to develop the commissioning specifications during the design stage. We use a "Division 17" added to the standard CSI format which normally contains divisions one through sixteen. There are those who argue that commissioning requirements should be included in individual divisions which specify equipment which require commissioning. However, we feel that keeping commissioning information in one place in the specifications is beneficial, especially in an environment where we are all still learning about the process.

The ASHRAE commissioning course referred to on page 1 teaches this method. The USDOE Model Guide Specifications[9] also uses this method in its extensive treatment of commissioning documentation[4].

In addition to writing the whole of Division 17, the CA will also write portions of Divisions 1, 15 and 16. Sections of Division 1 that would be modified to include information about commissioning include the following (actual numerical designations may vary slightly):

- *01011—Summary of the Project*
- *01030—Alternates*
- *01310—Construction Progress Schedules*
- *01330—Submittal Procedures*
- *01400—Quality Requirements*
- *01730—Operation and Maintenance Data*
- *01770—Closeout Procedures*

Division 15 sections include:

- *15000—General Provisions/Testing and Balancing*
- *15990—Testing, Adjusting and Balancing*

Division 16 sections include:

- *16000—General Provisions*

References 4 and 5 provide examples of narrative that can be included in these sections to inform the contractor of commissioning requirements.

The Preliminary Commissioning Plan

As the CA is writing the specifications for commissioning, they develop the Owner’s original commissioning procedure (see Appendix 4) into a *preliminary commissioning plan*. This commissioning plan extends the owner’s original system-by-system commissioning procedure into a scope of work naming actual components and systems in the design documents. Rather this interim plan is incorporated into the specifications to give the contractor the best possible idea of their part in the process. After the bid is awarded and submittals are approved, the CA writes the formal commissioning plan that completely describes the commissioning work (see below: “Starting Construction Right-The Early Stages”).

The preliminary commissioning plan is one document of six that define the commissioning process from beginning to end. These documents start with the Design Intent Narrative and end with the Commissioning Report. *Figure 6* (Appendix 6) lists these guiding documents and their part in the overall process.

The Commissioning Process—The Bidding Stage

The call for bids is a brief but important time in the commissioning process. This is the first opportunity to bring the construction contractor(s) into the process and it is vital that the contractor cooperate in the commissioning process if the team is to reach the goal of a quality building. The inspection and testing required by the CA is performed by contractor personnel. It takes contractor time and it costs the contractor money. It also saves the contractor time and money through reduced callbacks and the early and fair resolution of problems (they are frequently not the contractor's fault!). Overall, the general contractor and sub-contractors will save more than they spend on commissioning, although they may not believe this at first.

As the bidders prepare their bids there will be questions about their role in commissioning. These questions should be answered by the CA either in writing or at a pre-bid conference, or both. Although commissioning is still a new and developing practice in the state of Montana, we have found that most contractors readily accept commissioning once they understand it. Furthermore, they accept the process much more readily if the CA exhibits a positive, helpful, cooperative approach right from the start. This is a key aspect of independent third party commissioning as opposed to contractor or design team commissioning. As *Figure 2* (Appendix 2) shows, one of our perceived drawbacks of independent third party commissioning is that the CA requires above average leadership and team building skills. Not all potential service providers have this, especially skilled technicians. For reasons similar to the above, we have also found that owner involvement is especially important when using third party commissioning.

In addition to answering contractor questions, the CA may need to answer questions for the design team. This is especially true if the project bids come in over the cost estimate. The CA may be called upon to evaluate the savings in commissioning costs that should result from cutting portions of the project out to make the required budget. Indeed, the CA may be required to help defend the commissioning process itself from elimination in view of a budget problem.

Most projects of a significant size ($1,000,000 or larger) follow a bid process similar to the following:

- Distribution of the Construction Documents (plans and specifications);
- Advertising for Bids in Newspapers;
- Conducting the Pre-Bid Conference/Walkthrough;
- Issuing the First Addendum—Answers to Questions from the Pre-Bid Conference;
- Issuing Subsequent Addenda for Questions Submitted After the Pre-Bid Conference;
- Collecting the Sealed Bids;
- Opening the Sealed Bids;
- Evaluating the Bids with Regard to Budget;

- Selecting Additive and/or Deductive Alternates According to the Budget;
- Rebidding if Required by Budget;
- Awarding the Project;
- The Contractor's Submitting of Insurance and Bond Certificates; and
- Issuing the Notice to Proceed.

Of these steps, the CA will have some involvement in the following:

- Conducting the Pre-Bid Conference/Walkthrough;
- Issuing the First Addendum—Answers to Questions from the Pre-Bid Conference;
- Issuing Subsequent Addenda for Questions Submitted After the Pre-Bid Conference;
- Evaluating the Bids with Regard to Budget; and
- Selecting Additive and/or Deductive Alternates According to the Budget.

When the owner or the owner's representative organizes the Pre-Bid Conference, the CA should be there to present a brief overview of the commissioning process and answer specific questions posed by the contractors.

As contractors accumulate more experience in commissioning, the CA's introduction during the pre-bid conference may not be so important. But at this juncture commissioning is still a new process for many contractors and the overview at the pre-bid conference may be their first (and hopefully, best) introduction to the process. The questions and answers that come out of this conference, including those related to commissioning, should be recorded in the minutes and issued in writing to all bidders as "Addendum 1".

Subsequent addenda will answer questions posed to the owner and design team after the pre-bid conference. They may or may not include commissioning questions. All commissioning questions posed by the contractor should be routed through the owner or owner's representative and then to the CA to assure that each response is sent in an identical form to all contractors and all members of the design team.

If the bids come in over the allowable budget, the usual procedure is to consider cutting portions of the project to bring it back within the budget. The design team may ask the CA to evaluate possible cost savings in commissioning resulting from cutting out portions of the project. There may be a proposal to cut commissioning completely in order to save money.

Proposals to cut commissioning because of cost should be met with resistance. The cost of the commissioning is usually some fraction of one per cent of the project cost and so is unlikely to swing a project back into budget. But even more important, it is wrong to compromise quality as a result of budget concerns. The A/E Division has argued this point successfully on several over-budget projects and we believe agencies, in general, agree with this logic. No matter what stays or goes, quality is mandatory.

Alternatively, if the bids come in lower than expected and additive alternates are chosen to add to the project, the CA should confirm that the required commissioning is included in the added work. The "Alternate" section of Division 1 of the specifications should advise the contractor that commissioning is included in the alternates. However, the CA should also confirm that their CA fee includes the commissioning of the additional work.

Starting Construction Right—The Early Stages

The beginning of the construction process includes the following commissioning related activities:

- *The Pre-Construction Meeting;*
- *The Development of the Construction Schedule and Schedule of Values;*
- *The Submittal of Equipment and Materials;*
- *Designation of the Contractor's Superintendent;*
- *Groundbreaking;*
- *The Completion of the Commissioning Plan.*

During the early stages of construction the CA continues to answer questions for the contractor and verify that commissioning is being integrated into the construction process. The best venue for this is the pre-construction meeting. The Division always includes the CA at the pre-con meeting and schedules a time for the CA to make a brief presentation describing the upcoming commissioning activities. The pre-con meeting provides an opportunity for the CA to meet more of the people who will be working for the contractor during the project. The CA presentation at the pre-con meeting should follow through with the presentation at the pre-bid conference, except with a concentration on the first few objectives in the list above.

The first item of discussion is the schedule. The schedule is actually *two* tasks: getting commissioning milestones placed on the overall schedule and including commissioning activities in the construction schedule of values. The construction schedule and schedule of values are key documents that allow the owner to track the construction process. Having commissioning included in these is a good way to confirm that the contractor is an active part of the commissioning team.

The CA reviews the overall commissioning process for the contractors and presents a tentative schedule showing only commissioning activities. This schedule gives the contractor an idea as to what commissioning information has to be included in the contractor's overall schedule. Examples of this type of schedule are included in Appendix 7-Schedules and Tracking Documents (*Items 1* and *2*). The general contractor is required to integrate the information shown on these preliminary schedules into the overall schedule of the project. In this way all sub-contractors are further notified as to the requirement for commissioning.

At the A/E Division, our construction manager will usually require that the general contractor submit the two schedules for approval with the first application for payment. If the schedules are not complete, the first payment is not made. When the schedules are submitted, copies are routed to the CA for his review with regard to commissioning milestones. The commissioning milestones shown on the tentative schedule of commissioning activities should be integrated into the overall schedule by the time the schedule is submitted for approval. Although it is true that this schedule may be revised many times before the bulk of the commissioning activities are accomplished, these activities should be a part of the schedule from the start. As other milestones are revised, the commissioning gets revised accordingly.

On large projects, the Division usually contracts with a professional construction manager to manage the owner's daily on-site construction responsibilities. This work includes accepting and processing requests for information, change orders, evaluating weather conditions and conducting construction meetings. This person or firm is termed the "on-site owner representative" or the owner's construction manager. As the project progresses, the CA and the owner's on-site representative need to coordinate their activities. There is a possibility of conflict in some of the work they do, but there is also a possibility of gained efficiency if they coordinate. Reference 10 discusses this interaction further.

As the contractor makes equipment submittals to the design engineer the project manager routes copies of the approved submittals to the CA for information only. The CA doesn't approve submittals (that's the engineer's job) but the CA does comment to the owner if there is anything in the submittals that appears seriously wrong. Opinions vary as to the degree of authority that the CA should have in the submittal process. If both the engineer and CA must approve submittals, this may slow the project down and/or create another area of conflict. Nonetheless it is sometimes done that way. In any event, the CA needs to be copied with the submittals to develop commissioning procedures.

Commissioning procedures include static inspection, start-up and functional test descriptions. The CA writes and assembles these procedures as part of the *commissioning plan* as equipment information is available from submittals. As the documents are completed, they should be submitted to the owner's PM for approval and then to the contractor for scheduling. Meetings between the CA and the contractor's construction manager serve to further clarify the intent of the process and keep the contractor involved.

The final draft of the *commissioning plan* is completed during the early stages of construction, after all equipment submittals have been approved and before equipment has arrived on the site. This plan is an extension of the Commissioning Procedure in Appendix 2 that is originally developed by the Division's commissioning staff. It starts with the requirements on a system-by-system basis and provides more detail based on the actual design and the actual equipment ordered. The commissioning plan developed at this point should have detailed information on the support required from contractor personnel. Specifically, each inspection and test should be annotated to show the responsible subcontractor. This document will be used by the general contractor's superintendent to schedule personnel to assist the CA in testing and inspection (see Figure 6—The Commissioning Plan Life Cycle).

Item 3 is an example of a concise listing of expected support requirements for commissioning activities that would be a part of the commissioning plan. The spreadsheet lists the sub-contractors by name and the corresponding equipment and system testing they will be required to support. This example is for start-up and functional testing. Similar documents would be used for inspection, training and other parts of the construction process.

The ASHRAE Commissioning Guideline 1-1996[3] and the USDOE Model Commissioning Plan and Guide Specifications (Section II)[9] provide further information on the development of the commissioning plan and how it fits into the planning and design process.

Acceptance-Static Inspection and Start-up

As the commissioning plan is completed, equipment is ordered and the building foundation and framing is beginning, the static inspection phase of commissioning begins. The static inspection phase lays the foundation for equipment start-up by confirming that equipment is installed so as to function in a safe and effective manner. In general, this includes factors such as:

- Equipment location according to plans and practical requirements, such as air handling units positioned so as to allow full access door openings for maintenance,

- The installation of instrumentation according to manufacturers requirements (such as laminar flow for flow sensing devices) and according to engineering requirements (such as duct pressure sensors located 3/4 of the distance to the furthest point in a VAV duct system),

- Sloping of drain piping as specified and pipe pressure testing,

- Factors such as sheave alignment, connection to power and other utilities and pipe and duct support.

For Montana projects these inspections are carried out by contractor personnel using checklists provided by the CA. These checklists incorporate manufacturer's requirements and basic items that would normally be done even without the commissioning process (one would hope), and therefore should not take a great deal more time than the normal checkout procedure.

Nonetheless these checklists are consistently neglected by contractor personnel and are usually only completed through the diligent monitoring of the CA. This usually begins with the CA actually completing the checklist for the installing tradesperson with the installer standing by. At some point the installers will begin to complete the checklists on their own. The inclusion of checklist milestones on the schedule and schedule of values helps emphasize the importance of this procedure to the contractor. The owner needs to reinforce this requirement by withholding contractor payment if necessary.

The helpful nature of the CA combined with the threat of delayed payments creates a "carrot-and-stick" approach that will produce results. As the contractor submits completed checklists, the CA spot-checks the forms. If the checklists have not been completed accurately, shortcomings will come to light as the group attempts to begin functional performance tests. If FPTs are cancelled and rescheduled the contractor is responsible for the cost of repeat testing (an important notice to be included in the specifications).

Examples of the main inspection activities are:

Piping and HVAC Ductwork:

Piping and ductwork should be inspected for correct installation and pressure tested. Testing domestic water and sanitary sewer piping is frequently a requirement of local building authorities and if they witness the tests, that is one less thing for the CA to do. On a recent Montana project using an out-of-state CA, the on site owner's representative agreed to witness these pressure tests which allowed the CA to structure trips to the site more effectively. Nonetheless, the CA needs to collect copies of all such tests for the report. Roof drains and (especially) below slab drains should be pressure tested.

Low-pressure (less than 3" spwg) ductwork need not be pressure tested. All ductwork should be inspected before insulation for correct joining and supports.

Air Handling Units and other Major HVAC Equipment:

AHUs, make-up air units, rooftop heating/cooling units and similar equipment should be inspected for mechanical items such as case drains, filter sealing, maintenance access, general air tightness and vibration isolator supports. Each piece of equipment should be inspected to assure that control devices such as sensors and actuators are complete per the energy management and control system (EMCS) points list and control diagrams, correctly located and completely and soundly installed. All electrical wiring is to be confirmed installed, in conduit, and tested to confirm power and correct polarity (for motor rotation).

HVAC plumbing should also be inspected for AHUs including coil connections, control valve locations, balance valves and test ports, bypasses and isolation valves. Lubrication for fan and motor bearings and movable supports should also be checked and mounting fasteners confirmed.

The EMCS is checked for complete installation of all devices throughout the building.

Finally, equipment is started up for the first time with required factory representatives in attendance. The equipment is tested at all required speeds and preliminary programming is completed as required to allow subsequent safe and easy starting. In the state of Montana, the main issues that we have seen arise during equipment start-up have been related to programming computerized controls on variable speed drives, chillers and similar equipment.

A complete list of inspection and start-up details is beyond the scope of this paper. Excellent lists can be found in references 1, 6, 9 (Part IV—Prefunctional Checklists), 11, 12 and 13.

Function is the Key—Functional Performance Testing

After equipment has been proved at start-up, functional performance tests (FPTs) are conducted to confirm that the pieces work together. Tests confirm that smoke causes AHUs to shut down and dampers to go into smoke control modes. Other tests assure that valves open on calls for heating and cooling and close when the setpoint is satisfied. Tests assure that AHU economizer cycles respond to outdoor air temperatures and indoor calls for cooling and that freeze protection actually shuts down the required equipment. AHU discharge temperature control is checked at the unit and also at the central energy management and control (EMCS) control station.

Dampers should be cycled and checked for leakage, especially face and bypass dampers on steam coils. All actuators should be stroked full open and full closed to check for binding, calibration and correct EMCS addressing.

Functional tests include checking EMCS parameters such as programmed addresses, sensor calibration factors, occupied/unoccupied programming and trend logging. Programming charts, sequences of operation, block wiring diagrams and wiring termination diagrams should be included in the report. All EMCS tuning variables such as response times, damping variables, delays and interlocks should be included in the report.

A sample of items included in the sub-contractor's test and balance (TAB) report should be checked for accuracy. If a substantial failure rate is encountered, all should be corrected and a different sample chosen for a repeat test at the contractor's expense. For instance, the Division generally starts with checking 20% of air distribution terminal devices such as grills and registers. We check all TAB parameters on major AHUs and associated return/exhaust fans.

See the inspection and start-up references listed above for further, extensive, collections of typical functional performance tests.

The functional performance tests are the heart of the commissioning process and they are also the most difficult and time consuming. This is when the team-building skills of the CA pay off. If the CA has succeeded in gaining the trust of the contractors by this time the chances of completing the FPTs in a timely manner will be markedly increased. The best method of earning and keeping a good working relationship with contractors is constant communication. As the FPTs proceed, the CA should constantly keep the contractors informed as to upcoming testing. An example of a notice of this type is the "Look Ahead Schedule" labeled as *Item 4* in Appendix 7.

As inspection and testing proceed, the CA will find a number of items that do not appear to work as intended. In some instances the intended operation is unclear. If the intended operation is unclear, the CA should submit a Request for Information (RFI) to the design team through the owner's construction manager in the same manner that a contractor would submit an RFI. After confirming the intended mode of operation, the CA can proceed with testing. The Division has found that RFIs usually point out subtle problems in design. These problems are usually easy to correct at little or no cost during construction but would develop into troublesome headaches for the O&M staff if not corrected. Examples are pump and AHU sequences of operation and contradictions in the drawings.

If equipment or systems are found to be malfunctioning, these problems should be listed on a form such as the Discrepancy Summary shown labeled as *Item 5* in Appendix 7. This spreadsheet indicates the test and item involved and also tracks the status of the problem as it is corrected. *Item 6* is a sample spreadsheet that assists the project manager in tracking the progress in correcting problems identified during the functional testing process.

Typical Commissioning Corrections

Appendix 8 contains a listing of problems identified and corrected in the course of commissioning. This listing is a mix of items identified in ten Montana projects over the period of 1996 through 1999. The buildings involved are all either new construction or extensive mechanical/electrical retrofits. Only the HVAC, fire alarm and emergency power systems were commissioned. The projects included a wide range of simple to complex HVAC systems serving office, classroom, hospital and laboratory buildings.

This list has been abbreviated significantly by the elimination of duplicate items. A total list of discrepancies would be about ten times the length of the one attached. Discrepancies are broken down by system type.

Passing the Baton-O&M Staff Training and the O&M Manual

As the systems are confirmed to work correctly, O&M staff training begins. Having been given a building that operates correctly and is complete with documentation as to wiring, function, sequences, programming, equipment, parts and testing and has maintenance access and accessories, all that is lacking is specialized training.

The CA takes the lead in inspecting and approving the O&M manual as to content and organization. The O&M manual may be in hard copy only or may have electronic data files as well. In either event, the format needs to be consistent with the existing agency maintenance plan (see below). The CA reviews the O&M manual and confirms approval by the operating staff and the design team. The completion of the O&M manual necessarily precedes the start of training because it is used as the training manual.

After the manual is ready, the CA coordinates training sessions with the sub-contractors and the operations staff. The sub-contractors actually present the training material. The CA attends all training sessions and sees to it that important issues are raised.

Obtaining the O&M manual from the contractor in a timely manner has proven to be difficult to do. Coincidentally with our commissioning efforts, we have worked to get the O&M manual information sooner in the construction process. If the manual is not complete until substantial completion (generally the same time as occupancy) it is difficult or impossible to perform adequate training in time for the agency staff to take over the building. This might lead to poor building performance in the critical first few months of building operation.

A better practice is to aim for the completion of the O&M manual as soon as possible after the last contractor submittal is approved. After the approval of the final submittal, all equipment should be ordered and O&M information should be on the way. If all equipment is on the site by approximately 50% of the construction schedule, the contractor should be able to assemble and complete the O&M manuals by about this time. Based on this rationale the Division now requires O&M manuals to be complete and approved as a requirement for any mechanical or electrical billing at 60% or more.

This requirement has met with protest. Mechanical and electrical contractors say that they never get O&M information prior to an order and sometimes it arrives only with the equipment. If it arrives with the equipment, the contractors further assert that they need the information for installation and so it is not available for the O&M manual. Notwithstanding these facts, our experience has been that the information can be obtained by the 60% billing with, perhaps, a little extra effort on the part of the contractors. If the actual manual is not complete until the 70% or even 80% stage, this is still workable and represents an important improvement over getting it at 100% completion.

The O&M staff should be consulted as to the desired organization of the O&M manual. The manual for a medium sized college lab building can be a half-dozen large volumes. Is it best to organize it by HVAC system, by floor, by program, in alphabetical order or something else? On multi-building campuses the staff may want a volume for each building. Frequently, the contractor will organize the manual any way the owner desires at little or no extra cost. But once it is done it will be practically impossible to have it done over differently.

Training is an area that can stand much improvement in modern construction. Commissioning is the ideal vehicle for this improved training. Commissioning improves training by assigning this responsibility to an independent third party professional, the CA. It further improves the training by taking it out from under the lowest rung of the construction hierarchy and mailing it a responsibility contracted directly to the owner (via the CA). Probably the biggest single factor making training more important than ever before is the explosive increase in the use of microprocessors and "PCs" in modern building construction. This technology is developing so fast that vendors are barely able to understand it. Design engineers and O&M staffs are guaranteed to not understand it unless good training is provided.

To improve EMCS training, Montana has instituted several fundamental changes. The first is to provide in the specifications for continuous training during the first year of building operation. This means between 8 and 24 hours of EMCS training during construction completion <u>and</u> monthly or bi-monthly training for a year after that. Further, the specifications are written to include all software necessary for remote monitoring by the Division in Helena and by the controls contractor wherever they are located. In this way, the Division or the contractor can provide fast, economical answers to questions or problems that arise during the first months of operation. The goal is to never let the O&M staff give up and switch the system onto "bypass."

Additionally, the initial EMCS training itself is conducted off-site, in a community college or "vo-tech" classroom especially built for computer training, as opposed to a noisy, cluttered, poorly lighted workroom without desks and chairs. The class is conducted in two parts. The first part uses general purpose demonstration software provided by the vendor and loaded into as many computers as there are trainees. In this way, the standard routines of switching screens, checking alarms, printing reports, changing setpoints, etc. can be practiced by everyone at once, "hands on". The second part of the training uses communication software to control the actual building systems remotely. In this way the trainees can take turns manipulating actual building systems in the quiet, undisturbed environment of the college classroom.

The Division also assigns video-taping (if used) to the CA. Many larger colleges and universities have communications courses dealing with video production and can provide an acceptable level of expertise at less cost than professionals. If the campus wants to provide these services, they need to provide a cost to the CA for inclusion in the proposal. As a general rule, we have found that it pays to use professional camera operators when video-taping. Good sound is as important as a good picture. Remember to turn off air compressors and other devices which can render instructions inaudible. Professional video-taping costs about $400 to $600/day and this does not include the cost of additional copies or any "production" work. Organize video tapes by system and/or building and don't hesitate to end up with a lot of tapes that may be only half or a third used. No one has the time to scroll through tapes looking for information.

<u>The Engineer's System Operation Narrative</u>

A new addition to the training procedure is the scheduling of a brief presentation by the design engineer to the operations staff that includes a description of the intended overall operation of the system. This is a time for the staff to ask the questions that remain after the construction process and were never completely clear on the design drawings. This team process often acquaints the design team with facets of the system operation that they were not aware of as well.

The result is a comprehensive "as-built" description of the system. This is recorded and transcribed to hard copy for inclusion in the O&M manual, the commissioning report or both.

The Commissioning Report

By the completion of training or shortly thereafter, the CA should have completed the Commissioning Report. The report is a collection of all that has gone on before. As such it contains copies of the following

- Design intent
- Basis of design
- The initial Owner's commissioning plan
- The final CA commissioning plan
- Signed-off checklists
- Signed-off FPT forms
- Requests for Information (RFIs)
- Deficiency reports
- Corrective Action
- Trend log description
- The engineer's operation narrative, and
- Planned off-season testing

The Commissioning report, the TAB report, the O&M manual and the as-built drawings and specifications form the bulk of the documentation that will be left with the O&M staff at the new building. Additional information on building controls that includes block wiring diagrams, as-built control diagrams and sequences of operation will also be included in either the commissioning report or the O&M manual.

A very good description of this material is included in The ASHRAE commissioning guideline (ref. 3). The ASHRAE guideline groups all of the above material into a common set called the Systems Manual." In fact, this set of information will be voluminous, it could fill a half-dozen binders. The Division collects the material as separate documents rather than collecting it together as a systems manual. Either way, the set contains the same information.

The First Year of Building Operation

At the completion of training, the contractor is granted substantial completion and the building is occupied. The Division includes a specific notice in the specifications indicating to the contractor that the successful completion of commissioning is a requirement for substantial completion.

Additional outstanding items are usually identified during the early months of occupancy, before final completion. And some other items come up during the one-year warranty period. But if the CA process has been followed, they are minor and can be readily handled by the trained O&M staff armed with documentation and training. Overall, the building will provide the working environment required for the occupants and the O&M staff can concentrate on establishing an effective preventative maintenance program that should work for the life of the building.

Seasonal Testing

Given Montana's weather extremes it is likely that certain parts of the building mechanical system can not be adequately tested due to the season of the completion. For instance, testing of a boiler system might be difficult in the summer and testing of a chiller and cooling tower might be difficult in the winter. Checking an outside air percentage is much easier when there is a substantial difference in temperature between the outside air and the return air.

For this reason, our commissioning plans include off-season testing to allow testing certain equipment under the best possible conditions. This requirement must be clearly spelled out in the specifications as it will require some contractor personnel to return to the site after the project is completed. It is also necessary to withhold money for this activity in addition to that usually withheld for warranty items.

EMCS Trend-Logging

During the completion of functional performance testing the CA is also asked to assist in the programming of the EMCS to include the trend-logging of a selected group of key performance indicators. These items usually include temperature indicators for boiler and chiller operations, duct pressures, outside air flows, and some typical VAV boxes and unitary equipment. This trend logging is a valuable part of the training program and allows the staff to get started on the right foot in insuring that the established building performance is maintained for the life of the building.

Continued CA Contact

It has been the experience of the Division that the CA is available for occasional, informal consultations throughout the warranty period or approximately the first year of building operation. This normally amounts to phone conversations. If complicated problems are encountered that involve conflicting opinions between the owner, designer and contractor or that relate to specific issues identified during commissioning, it may be worthwhile for the Division to contract with the CA for additional services. It is unreasonable to expect the CA to provide (extensive) services that were not identified in the original contract without compensation.

If the owner was concerned about the ability of the O&M staff to operate the building in the first year of operation, periodic monthly training sessions could be attended by the CA who would consult with the staff about trend-log results and other emerging issues at the same time. The off-season testing would be coordinated with one of these site visits.

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[1] ASHRAE can be contacted in Atlanta, GA at 404-636-8400 or e-mailed at edu@ashrae.org. The ASHRAE web site can be accessed at www.ASHRAE.org.

[2] The Procurement of Services for Architecture, Engineering and Land Surveying is state law and is included in the Montana Code Annotated (MCA), Title 18, Chapter 8, Part 2.

[3] The BCA has a good Internet website for those interested in commissioning. It is located at www.bcxa.org.

[4] The USDOE document is surely the "grand daddy" of all commissioning guidelines. It is available free of charge over the Internet and takes up about three large three-ring binders. It is highly recommended for anybody involved with commissioning.

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1. Kao, James Y. March, 1992. “HVAC Functional Inspection and Testing Guide” Paper No. NISTIR 4758, National Institute of Standards and Technology of the US Department of Commerce.

2. Portland Energy Conservation, Inc., “What Can Commissioning Do For Your Buildings” Sponsored by PacifiCorp. Contact Carolyn Dasher at (503)-248-4636 or peci@teleport.com.

3. “The HVAC Commissioning Process”, Guideline 1-1996 (supersedes Guideline 1-1989), Approved June, 1996. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, Georgia.

4. Heinz, John A. and Casault, Rick. 1996. “The Building Commissioning Handbook”, The Association of Higher Education Facilities Officers, Alexandria, VA.

5. Tseng, Paul. July, 1998. “Montgomery County Maryland Building Commissioning Program and Contractor Quality Control”, Montgomery County Government, Rockville, MD.

6. Oregon Office of Energy. March, 1997, “Commissioning for Better Buildings in Oregon.” Prepared by PECI, Portland, Oregon.

7. Stum, Karl and Haasl, Tudi, Portland Energy Conservation, Inc. (PECI). “Quality Control for the Simple Project.” Proceedings of the 1996 Northwest Conference on Building Commissioning in Portland, Oregon, Session 5.

8. US Army Corps of Engineers. July, 1995. “Engineering and Design-Systems Commissioning Procedures,” Publication Number ER 1110-345-723. Available on the Internet at www.usace.army.mil/inet/usace-docs/eng-regs.

9. US Department of Energy, Seattle Regional Support Office. February, 1998. “Model Commissioning Plan and Guide Specifications.” Available online—contact PECI at (503)-248-4636 for details.

10. Wilkinson, Ronald. 1998. “CA, meet CM, et al.” *Engineered Systems* December.

11. Bonneville Power Administration, US Department of Energy. November, 1992. “Building Commissioning Guidelines-Second Edition.”

12. Sheet Metal and Air Conditioning Contractors National Association, Inc. (SMACNA). October, 1994. “HVAC Systems Commissioning Manual-First Edition.”

13. National Environmental Balancing Bureau (NEBB). January, 1993. “Procedural Standards for Building Systems Commissioning-First Edition.”

Although not specifically referenced, these documents provide a good overview of the commissioning process:

1. US General Services Administration and US Department of Energy. August, 1996. "Building Commissioning Guide." Prepared by Enviro-management & Research, Inc., Arlington, VA.

2. George Butler and Associates, Inc. 1997. "Building Systems Commissioning—Understanding the Integrated Process and Benefits." Presented at the 1997 National Association of State Facilities Administrators Conference.

3. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (800-DOE-EREC. May 1998. "Building Commissioning-The Key to Quality Assurance." Prepared by PECI, Portland Oregon.

The Florida Sustainable Communities Center/e Design has a good website for general commissioning information and other information on indoor air quality and sustainable architecture. They can be visited at: **http://edesign.state.fl.us**

APPENDIX 1

Policy Guidelines

POLICY GUIDELINES

This section of Policy Guidelines is included for the use of state and local governments in developing policies, standards or legislation relating to commissioning public buildings. It has become apparent that commissioning enhances the quality of buildings and that quality buildings are a necessity for the efficient use of the taxpayer dollar. This information is presented for use in drafting policies that attach the commissioning procedure to new building construction.

No attempt will be made here to write a policy regarding commissioning. Rather, the guidelines below constitute a checklist that can be used when considering such a policy. Because every governing body is different with regard to the size and type of buildings it constructs, these guidelines will have to be incorporated into procedures that match the public needs. This task is left to the reader.

Most state and local governments have an agency that is specifically tasked with planning and budgeting for capital construction projects. This agency will have the primary responsibility to manage the commissioning process. This agency goes by different names (in Montana it is the Architectural and Engineering Division of the Department of Administration). In these guidelines, the term *Capital Planning Agency (CPA)* will be used as a standard reference to this organization.

Commissioning should be considered for every project of sufficient size to be a part of the CPA's capital construction program. In Montana this program is called the Long Range Building Program. In other states and cities it has different names. But in all cases the program centers on larger capital projects for new buildings and extensive remodels and additions for existing buildings.

Commissioning Defined:

Commissioning is defined as a planned, collaborative and systematic process of inspection and testing conducted to confirm that a structure and its sub-systems perform as designed and as expected by the building occupants.

Managing the Commissioning Process:

The CPA should manage the commissioning process and assure that commissioning is included in project planning and budgets where appropriate.

Planning for Commissioning:

Capital construction programs usually have standardized forms containing budget information for each project. These forms may be filled out by a requesting agency or by a planner within the CPA. Commissioning should be added as a line item to this form to encourage agency planners and staff engineers to consider commissioning and to assure that, if desired, it is funded. The CPA should confirm that this form contains funding for the planned commissioning when it is required.

New building projects should be commissioned if they are of an estimated construction cost of $2.5 million or more and are of average or complex construction. Average complexity includes K-12 school and office buildings. Complex construction includes hospitals and university laboratory buildings. “Streamlined” commissioning performed by the A/E design team (mainly the engineering consultant) may be used on smaller projects and/or projects with simplified HVAC systems.

Use of an Independent Third Party Commissioning Authority:

Independent third party commissioning should be utilized on all projects unless the projects are small and of average construction (see above) in which case streamlined commissioning services may be provided by the A/E design team. On larger, more complex projects commissioning procedures should be developed, supervised and documented by an independent Commissioning Authority (CA) in private practice, contracted directly to the owner. Actual testing procedures are to be conducted by contractor personnel as part of their contract to provide and install equipment and materials.

The CA should be selected based on qualifications and not on the basis of a low bid, in a manner similar to architectural and engineering consultants, from a list of qualified service providers maintained by the CPA.

CA firm qualifications should include a staff of professional engineers and field technicians, participation in national commissioning organizations or conferences and continuing education.

The CA should be selected at the same time as the design team to allow the integration of commissioning services throughout the project. Commissioning should continue through construction and acceptance and should include trend logging and alternate-season testing approximately six months after substantial completion and building occupancy.

The CA fee should be negotiated similar to engineering fees and may be negotiated in two parts. The first part should include commissioning services for planning, design and bidding and the second part should include services for construction, acceptance and off-season testing.

Commissioning Deliverables:

The CA should provide the following deliverables in the course of commissioning the project:

- The Design Intent document containing the building occupants’ expectations of building operation. This document is to be prepared and revised as required by the design team and is to be checked by the CA and included in the Commissioning Report,

- Portions of the construction specifications including portions of CSI standard Divisions 1, 15, 16 and 17, where division 17 is dedicated to commissioning scope and procedures. If Division 17 is used for other purposes, another division should be designated as dedicated to commissioning requirements. This information is also known as the Preliminary Commissioning Plan,

- The final Commissioning Plan containing all required forms and procedures for the complete testing of all equipment and system included in the scope of work,

- The Commissioning Report contained all documentation of testing and inspection, all reports of deficiencies and related correspondence.

Commissioning Services:

In addition to providing the above, the CA shall provide at least the following services in addition to the services required for on-site testing and inspection:

- Attend standard construction document reviews that are attended by the owner and provide written comments for all reviews conducted by the owner;
- Attend the contractor's pre-bid inspection (walkthrough) and present the commissioning process to the contractor's present;
- Attend the pre-construction conference and present up-dated commissioning information to the construction team;
- Attend the substantial completion walkthrough or final inspection and present a report of outstanding deficiencies;
- Attend a final debriefing with the owner and agency representatives to discuss the final commissioning report.

Requirements of the Design Team:

The design architect and sub-consultants should be informed of the commissioning process during their interview for the project and/or by specific description in the Owners programming documents, prior to their being retained for design services. They should be made fully aware of their responsibilities in the commissioned project, which include all responsibilities in a conventional design-bid-build project plus the following:

- The development and production of the Design Intent (DI) narrative which states, in detail, the function of the building as required by the future occupants,
- The development and production of the Basis of Design which, in the same format as the DI, states the specific methods and design parameters that will be used in accomplishing the design intent,
- Present the System Operation narrative at project training sessions to fully explain the intended operation of the building and its sub-systems and provide this material in written form for the commissioning report,
- The incorporation of specifications listed above and written by the CA into the specifications of the construction documents,
- Addressing all questions and comments of the CA as they would address questions and comments from the Owner.

Commissioning as a Requirement for Substantial Completion:

The successful completion of commissioning (except for trend logging and off-season testing) should be a requirement for the granting of substantial completion for the project and for the occupancy of the building. This includes all training and approved O&M manuals.

APPENDIX 2

Why and How to Commission

WHY COMMISSION?

Pre-Oil Embargo

- Mechanical Systems Oversized
- HVAC Relatively Simple
- No Computers
- Few IAQ Problems
- No Energy Codes
- Engineers Amply Compensated based on simpler systems

Post-Oil Embargo

- Little Margin of Error in Systems
- HVAC Complexity Increases and Building Cost Doesn't
- Computers Everywhere
- IAQ Problems due to new materials and increased awareness
- Extensive Energy Codes
- Engineers squeezed on fees

Figure 2: Advantages and Disadvantages of Delivery Methods

Commissioning Agent	Advantages	Disadvantages
Independent Cx Service Provider Contracted to Owner	Un-Biased Third Party Judgement Direct Responsibility to Owner Direct Communication With Owner Professional Staff Includes "Systems" viewpoint and good communications	Additional Contract Adminsitration Restricted Selection Process for Public Entities CA Requires Leadership and Team Building Skills
Owner's In-House Commissioning Staff	Un-Biased Third Party Judgement Direct Responsibility to Owner Direct Communication With Owner Possible Lower Cost Than Consultants	Additional Personnel for Owner Scheduling and Supervisory Work for Owner
Construction Manager (on site)	Un-Biased Third Party Judgement Direct Responsibility to Owner Direct Communication With Owner Combined Contract with CM	May Lack Communications Skills May Lack Overall "Systems" training and skills
Independent Cx Service Provider Subcontracted to Design Architect	Architect Does Contract Administration CA More Familiar With Design	Biased Approach to Design Indirect Communication With Owner Poor Communication of System Issues Payment Problems
General Contractor	Contractor Administers Contract CA More Familiar With Installation All Responsibility With Contractor Good Understanding of Actual Operation	Biased Approach to Installation Indirect Communication of CA With Owner Indirect Payment From Owner to CA
Mechanical Sub-contractor	Best knowledge of mechanical systems Reduced costs by combining Cx with normal check-out	No independent third party inspection Lack of skills in evaluating programming Lack of "disinterested" position requires maximum owner oversight

APPENDIX 3

Commissioning Authority Selection

STATE OF MONTANA
COMMISSIONING AUTHORITY SELECTION PROCEDURES

1. Architecture and Engineering Division (A/E Division) determines need for commissioning and recommends such to using Agency. Requirement for commissioning may be a part of Long Range Building Program project scope authorized by legislative action. Upon establishing the requirement for commissioning, a firm serving as Commissioning Authority (CA) shall be selected. CA selection shall take place at the same time as the selection of the design team or as shortly thereafter as possible.

2. A/E Division develops and/or reviews the proposed scope of commissioning procedure for project including available funding, authorization, etc. The A/E Division assigns a Project Manager (PM) to the commissioning portion of the project. The PM develops the official scope of work for the CA which serves as a written record of the CA responsibilities and is the guideline for the negotiation of the CA fee.

3. Based on the scope of work, the A/E Division shall determine what type of services the CA is to perform and shall select the appropriate route of procurement to be as either Consultant, Architect/ Engineer or a Construction Contractor.

    a) Commissioning Authority as Consultant:

        Selection shall be in accordance with Title 18, Chapter 8, Part 1 of MCA. Consultant means the human service of studying or advising an agency under independent contract. If the CA is performing actual testing, balancing, adjusting, correcting, or other action which may be determined to be an actual part of construction rather than a study, the CA should be either a licensed Architect or registered Professional Engineer. For studies or advising where the proposed contract will exceed $10,000, A/E Division will notify all consultants on bid list. The notice shall contain all items listed in 18-8-105 MCA.

    b) Commissioning Authority as Architect/Engineer:

        Selection shall be in accordance with Title 18, Chapter 8, Part 2 of MCA. To use this section, CA shall be either a licensed Architect or a registered Professional Engineer. Regular established A/E selection procedures shall be followed from this point where estimated costs are expected to be more than $10,000. Where the estimated cost is $10,000 or less, the services may be procured by direct negotiation with a single firm. Interested firms should summarize their qualifications on Form 114 and submit same to the A/E Division. Form 115 shall be submitted if the requirement for commissioning is advertised in quarterly mailings.

    c) Commissioning Authority as Construction Contractor:

        Selection shall be in accordance with Title 18, Chapter 2, Part 3 of MCA. Where the estimated cost is $25,000 or less, three informal bids shall suffice as providing competition. Where the estimated cost is $5,000 or less, the services may be procured by direct negotiation with a single Authority.

APPENDIX 4

Defining Scope and Soliciting the CA Fee Proposal

MONTANA ARCHITECTURE AND ENGINEERING DIVISION
CAPITOL BUILDING RENOVATION—A/E No. 95-30-03-03
COMMISSIONING PROCEDURE

Original—December 21, 1998

OVERVIEW:

Commissioning is defined as the planned and documented process of assuring and confirming that a structure and its sub-systems have been installed, started up, tested and adjusted so as to meet the standards defined by the construction documents and also the owner's needs as defined in the project program. Although commissioning usually begins during the design stage of a project, this commissioning project will begin after bidding but before the award of the bid and will continue through final acceptance of the building. The quality assurance of training, operations and maintenance documents and other final documentation is included in commissioning.

The capitol renovation project includes the nearly complete demolition and replacement of the existing mechanical and electrical systems. Specifically this includes:

- The demolition of an existing small chiller in the capitol building and the construction of a major addition to the existing detached boiler plant to house the new and larger chiller, cooling tower, pumps and other equipment,
- The replacement and addition of major air handling units,
- The installation of a new DDC control system,
- The replacement of the primary and secondary electrical power systems,
- The replacement of nearly all existing cabinet heater/coolers, exhaust fans and other minor equipment,
- The reuse of existing heating/cooling piping in the core areas and the installation of new piping in the wings,
- The installation of new main piping and power supply utilities in the existing tunnel,
- The replacement of the existing voice, data, audio and video transmission infrastructure.

The value of the mechanical portion of the work, including the items listed above, is approximately $7,000,000. There will be additional architectural, historical renovation and related work totaling between $4,000,000 and $8,000,000 included in the project as well.

COMMISSIONING TEAM:

This commissioning includes the combined efforts of the following groups:

- The maintenance and operating staff of the capitol building (represented by Doug Olson at General Services Division (GSD)—444-3060),
- The Montana Architectural and Engineering Division (the Division, Ron Wilkinson—444-3331),
- The project mechanical/electrical consultant, Summit Engineering Group, Great Falls (represented by Greg Cunniff—452-9970),
- The commissioning authority (**CA**) and
- The general contractor and mechanical, electrical and controls sub-contractors (the Contractor). At the time of this writing, Dick Anderson Construction of Helena is the apparent low bidder. Big Sky Mechanical is the designated mechanical sub-contractor and Mountain States Electrical is the designated electrical sub-contractor. Plumbing, sheet metal, controls and test and balance will be under the mechanical sub-contractor.

BUILDING SYSTEMS INCLUDED IN COMMISSIONING:

All mechanical systems and some electrical systems in this building (as shown on the construction plans) are included in the commissioning process. Specifically, these include:

- Plumbing systems, including all pressure tests, cleaning, domestic water heating devices, water softening, etc. (if included in the design). Includes writing narrative records or collecting standard documents for all pressure tests, cleaning, flush-out and sterilization and the inclusion of these in the Commissioning Report;
- All systems associated with new **and existing** air handling units (AHUs) and their components, including:

    - Hydronic heating and cooling coils
    - Return fans (where used)
    - Filter sections
    - Economizer sections
    - Controls (see below)

- Other major supply and exhaust fans, including checking 100% of units for correct air volume and testing all associated dampers, flow switches, damper switches, freeze ‘stats etc.;
- Air conditioning chillers and related systems including controls, pumps and tanks, equipment, cleaning, initial (start-up) water treatment, etc. Includes writing narrative records or collecting standard documents for all pressure tests, cleaning and sterilization (if required) and the inclusion of these in the report;
- New steam piping from existing boilers to renovated machine rooms including testing, cleaning and condensate handling systems (existing steam boilers **not** included),
- Hydronic heating and cooling water circulating systems including pumps, coils, finned pipe radiators, unit heaters, etc. To include checking initial cleaning, water treatment and start-up, pressure regulation, make-up water, air control, etc. and also writing narrative records or collecting standard

documents for all pressure tests, cleaning, flush-out and sterilization and the inclusion of these in the report;

- DDC Control System including the main control station and/or PC based front-end, the testing of 40% of VAV box, cabinet heater and similar minor equipment addresses, calibration and controls. Also the collecting of all calibration data for inclusion in the report.
- HVAC Testing, Adjusting and Balancing, including the testing of 40% of all terminal devices and the review and certification of the T&B report.
- Testing all interlocks between air moving equipment and fire alarm systems including smoke dampers, and documenting for inclusion in the report,
- Reviewing O&M manuals,
- Scheduling, attending and augmenting training sessions presented by the contractor,
- Compiling all DDC controls calibration data, hydronic pressure test data, cleaning and sterilization data, boiler cleanout, initial water treatment and start-up data and other test records and data and including this in the report.

Electrical systems included:

- Confirmation of correct operation of Variable Frequency Drives during motor starting, duct pressurization control and manual bypass. Collecting and certifying all programming parameters for drives for inclusion in the report.
- Confirmation of correct operation of electrical interlocks associated with equipment above.

COMMISSIONING PROCEDURE:

Pre-Construction Phase:

*Note: The design stage of this project has passed and the project has been bid and is now pending award. However, the **CA** is asked to perform the following services during the submittal period and bring problems to the attention of the commissioning team through the Request for Information (RFI) process.*

- During the design stage the **CA** does the following:

- Checks the construction documents to assure that the equipment and systems are accessible for commissioning and that the systems are designed such that they can be commissioned, balanced and maintained,

- Develops a commissioning plan for review by the Commissioning team which shows the relative scheduling and extent of resources required from the team and, especially, the general contractor and sub-contractors.

Construction Phase:

- Revise the commissioning plan as required by changes in the design during the construction process and further detail the plan.

- Review submittals and shop drawings, especially those related to controls, to confirm that equipment and operation sequences are consistent with design document requirements. Review and comment on test and balancing specifications to begin solving anticipated problems before T&B starts,

- Witness and/or verify all piping and equipment pressure tests, piping cleaning and other tests and procedures required in the specifications. Write and/or collect all documentation pertaining to these tests and procedures for inclusion in the commissioning report.

- Develop Static Installation and Pre-start-up checklists. Distribute these to the contractor and verify that they have been correctly completed prior to subsequent activities such as equipment start-up, flushing, cleaning, etc. Recheck equipment and systems as required until they meet design criteria.

- Develop, and submit for review, the functional performance tests that are used during the Acceptance phase.

Acceptance Phase:

- The **CA**, in the company of representatives of the Division, Contractor and/or consultant, will perform Functional Performance Tests (FPTs) on all principle pieces of equipment and systems and a representative sampling of smaller, repetitive equipment and systems. The **CA** will retest and recheck equipment and systems as required until they meet design criteria. Retests beyond the original scope of the commissioning will be billed to the Division as additional services, the cost of which will be deducted from payments to the Contractor.

- Systems found to be uncommissionable due to design errors and/or omissions will be redesigned by the design consultants at their expense.

- The facility operating staff will begin planning to witness the commissioning tasks for training purposes when the list of commissioning tasks is available for review.

- The **CA** will schedule and coordinate training by the contractor. Members of the **CA** will attend all training sessions and assure the quality of the sessions by asking questions and otherwise adding to the process.

- As part of the commissioning fee proposal, the **CA** shall provide a separate cost for videotaping training. This includes the taping of principal pieces of equipment and samples of smaller pieces of equipment and identifying the names and locations of sub-components and sub-systems. The **CA** should sub-contract this service unless trained personnel are available within the firm (past costs have ranged from $400 to $600 per day for VHS taping for a single set of tapes). The **CA** will label the videotapes and submit the tapes to the Division for approval prior to Substantial Completion.

- The **CA** will review the O&M manual and submit to the architect/engineer consultant for release to the Owner.

- The **CA** will complete the Commissioning Report and submit draft copies to GSD, the Division and the design consultants for review. The **CA** will attend a review meeting to address final comments and issue the final report in these quantities: **(2)** copies to GSD, **(1)** copy to the design consultants and **(1)** copy to the Division.

- The facility operating staff will conduct trend logging, or contract with others to conduct logging, to confirm that the commissioned systems operate correctly in a variety of seasonal and building usage environments for one year or more after commissioning is complete. The **CA** will return to the site during the next heating/cooling season, retest key systems during extreme outdoor temperatures (including at least the economizer sections of the two AHUs, discharge set points and associated controls) and issue a brief report memo of the findings to the parties listed above.

- Contractor will correct building system deficiencies covered under warranty which are shown to be deficient based on trend-logging and/or delayed commissioning.

This program was written by Ron Wilkinson, Montana A/E Division. Please direct comments on the above procedure to Ron Wilkinson at 444-3331 or e-mail to rwilkinson@state.mt.us.

Note: A copy of a sample Commissioning Fee Estimation Sheet is included for your reference. This format may be used, or a different format may be used which includes these areas. Provide additional detail by breaking down costs during construction and acceptance phases on a “by system basis”, such as; “AHU 1”, “MAU 3”, or “check 70 VAV boxes” or “verify DDC addresses.” Numbers are provided in the sample spreadsheet for example only and do not refer to this project.

COMMISSIONING SERVICES FEE ESTIMATION and PROPOSAL WORKSHEET

Project Phase	Quantity	Miles/Hours	Unit Cost	Total Cost
DESIGN PHASE				
Inspect site and discuss with owner				$
Review and confirm design intent narrative				
Perform design reviews				
Attend final review meeting				
Develop and submit written design comments				
Travel: No. trips @ miles/trip				
No. trips@hours/trip				
Other:				
Subtotal Design Phase				**$**
BIDDING PHASE				
Attend pre-bid walkthrough & explain commissioning				$
Travel: No. trips @ miles/trip				
No. trips@hours/trip				
Other:				
Subtotal Bidding Phase				**$**
PRE-CONSTRUCTION PHASE				
Attend Pre-Con meeting				$
Review equipment submittals				
Develop commissioning schedule				
Develop commissioning plan				
Develop static inspection checklists				
Develop equipment start-up checklists				
Travel: No. trips @ miles/trip				
No. trips@hours/trip				
Other:				
Subtotal Pre-construction Phase				**$**

COMMISSIONING SERVICES FEE ESTIMATION and PROPOSAL WORKSHEET

Project Phase	Quantity	Miles/Hours	Unit Cost	Total Cost
CONSTRUCTION PHASE				
Issue and verify static inspection checklists				$
Finalize commissioning schedule and plan				
Witness equipment start-up				
Develop functional performance tests (FPTs)				
Travel: No. trips @ miles/trip				
No. trips@hours/trip				
Other:				
Subtotal Construction Phase				**$**
ACCEPTANCE PHASE				
Witness FPTs				$
Submit deficiency reports				
Schedule and attend training				
Review O&M manuals				
Review as-built drawings				
Assemble final report				
Travel: No. trips @ miles/trip				
No. trips@hours/trip				
Other:				
Subtotal Acceptance Phase				**$**
SUPPLEMENTAL SERVICES				
Perform delayed testing in opposite season				$
Travel: No. trips @ miles/trip				
No. trips@hours/trip				
Other:				
Subtotal Supplemental Services				**$**
ADDITIONAL SERVICES				
Video-tape training sessions				$
Other:				
Subtotal Additional Services				**$**
Total Commissioning Fee				**$**

University of Montana
Pharm/Psych Building Addition
Commissioning Scope of Work
Air Distribution Systems

		Static Tests		*Startup*		*Functional Performance Tests*				
System	***Procedures/ Forms***	***Mechanical Inspections***	***Flushing/ Press. Test***	***Equipment Startup***	***Control Calibration***	***Control Sequences***	***Performance Verification***	***Balance/ Flow***	***Final Report***	***Total Hours***
(9) Cabinet Heaters	2	2			2	2	2		2	12 0
(13) Unit Heaters	2	2			2	3	3		2	14 0
(6) Humidifiers	2	2			2	3			2	11 0
Domestic Water Distribution	1	2	2					2	2	9 0
Natural Gas Distribution	1	2	2						2	7 0
Drain, Waste, Vent	2	4	4						2	12 0
Chilled Water Distribution	2	2	4		2	4	2	2	2	20 0
Hot Water Distribution	2	2	4		2	4	4	6	2	26 0
Condensate Return System	1	1	2				2		2	8 0
Ground Water System	1	1	2	2	2	4	2	2	2	18 0
Fire Protection	1	2	2						2	7 0
Fire Alarm	2						12		2	16 0
Emergency Power	2			2			6		2	12 0
Building Pressurization	4						6		2	12 0
EMCS System	2						6		2	10 0
	27	**22**	**22**	**4**	**12**	**20**	**45**	**12**	**30**	**194 0**
Field Hours	**137**									

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University of Montana
RJ Wilkinson Building Addition
Commissioning Cost Summary

	Hours	Labor Cost	Misc. Expenses	Total Cost
Commissioning Specifications	40	$2,200		$2,200
Design Review	24	$1,320		$1,320
Design Review Meeting	8	$440		$440
Pre-Bid Walk-Through	8	$440		$440
Pre-Construction Meeting	8	$440		$440
Draft Commisioning Plan	16	$880		$880
Scope Meeting	8	$440		$440
Final Commissioning Plan	4	$220		$220
Submittal Review	4	$220		$220
Deficiency Reports	16	$880		$880
Training and Videotaping	32	$1,760		$1,760
O & M Review	8	$440		$440
As-Built Review	4	$220		$220
Delayed Testing	16	$880		$880
Printing, etc.			250	$250
Field Testing (From pages 2-5)	453	$24,915		$24,915
Procedures and Forms (From pages 2-5)	66	$3,630		$3,630
Final Report (From pages 2-5)	72	$3,960		$3,960
Travel Time	100	$4,489		$4,489
Mileage			2305	$2,305
Per Diem			3281	$3,281
	887	**$47,774**	**5836**	**$53,610**

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COMMISSIONING SERVICES REQUEST FOR PAYMENT

NAME AND LOCATION OF PROJECT:		MONT A/E #	
FIRM NAME AND ADDRESS:		PAY REQUEST #	
	Contract Amount	Percent Complete	Amount Due
AMOUNT FOR DESIGN PHASE	$	%	$
AMOUNT FOR BIDDING PHASE	$	%	$
AMOUNT FOR PRE-CONSTRUCTION PHASE	$	%	$
AMOUNT FOR CONSTRUCTION PHASE	$	%	$
AMOUNT FOR ACCEPTANCE PHASE	$	%	$
ADDITIONAL SERVICES			
			$
			$
			$
			$
			$
Fee Earned to Date			$
Less 10% Retainage			$
Subtotal			$
SUPPLEMENTAL SERVICES			
			$
			$
			$
			$
			$
Total Fee Earned			$
Less Previously Invoiced			$
Total Due This Invoice			$

I hereby certify that this submitted claim for payment is correct, true and just in all respects and that payment or credit has not previously been received. I further warrant and certify by submission of this claim that all previous work for which payment has been received is free and clear of all liens, claims, security interests or encumbrances in favor of the Architect/Engineer, subcontractors, consultants, employees, material suppliers or other persons or entities and do hereby release the Owner from such.

Submitted by:
Architect/Engineer Name

Approved by: Architecture & Engineering Division

Title: Name

APPENDIX 5

Commissioning Fee Guidelines

PINE HILLS YOUTH CORRECTIONAL FACILITY Cx BUDGET

(revised per actual bids 9/16/97)

Project Division	Budget Estimate 7/3/1997	Actual Bid 9/16/1997
New Building	$7,733,400	$7,733,400
Remodeling	$369,700	$369,700
Utilities	$715,380	$715,380
Demolition	$84,500	$84,500
Site Development	$488,350	$488,350
Subtotal	$9,391,330	$8,011,060
8% Contingency	$751,306	$640,885
Subtotal w/contingency	$10,142,636	$8,651,945
A/E Fees	$1,119,452	$1,119,452
Furnishings and Equipment	$395,800	$395,800
Asbestos	$75,000	$75,000
Advertising, testing, artwork, and misc.	$217,892	$217,892
Total	**$11,950,780**	**$10,460,089**

New Building Breakdown				Cx %	Cx Cost
			Total		
HVAC	$1,203,188		$1,203,188	2.00%	$24,063.76
Plumbing	$652,729	(use 1/2)	$326,364.50	2.00%	$6,527.29
Fire Alarm	$40,688		$40,688	2.00%	$813.76
Security	$203,439	(not included)			
Electrical	$699,830		$699,830	1.00%	$6,998.30
Subtotal			**$2,270,071**		**$38,403**

Travel and Misc.	$15,000
Total expected Cx Authority fee	**$53,403**
Actual Cx Authority Fee	**$49,201**

Utility Tunnels--No Commissioning at this time				Cx %	Cx Cost
Mechanical	$402,099		$402,099	2.00%	$8,042
Electrical	$271,360		$271,360	1.00%	$2,714
Plumbing	$55,040	(use 1/2)	$27,520	2.00%	$550
Watrer Service	$17,920	(use 1/2)	$8,960	2.00%	$179
	Total estimated Cx Authority cost for tunnels				**$11,485**

COST OF COMMISSIONING NEW CONSTRUCTION

1996 GSA "Building Commissioning Guide"

Entire Building (HVAC, Controls, Elect. and Mech.)
.5 to 1.5% of total construction cost

HVAC and Associated Controls
1.5 to 2.5% of mech. system cost

Electrical Systems Commissioning
1% to 1.5% of elect. system cost

Canadian Public Schools (ca 1994)

1.7 to 3.8% of system construction cost

British Columbia Building Corporation Study (1989)

1.3 to 5.1% of mechanical construction cost

University of Washington (1994)

1 to 2% of electrical system cost, plus
2 to 3% of mechanical system cost

Does not include travel or per diem
Can decrease to 2/3 or increase by 2/3 for simple and complex projects

Sheet Metal and Contractors National Association (SMACNA).1994, "HVAC Systems Commissioning Manual"

2 to 5% of HVAC Construction Cost

COST OF COMMISSIONING NEW CONSTRUCTION *(cont'd)*

US Department of Energy, Rebuild America Program.

1998, "Building Commissioning, the Key to Quality Assurance"

1.5% to 4% of mechanical cost for HVAC/controls, and

1.5% of electrical cost

1998 DOE Rebuild America "Commissioning Guide"

Total Building Commissioning (controls, electrical and mechanical systems)

.5 to 1.5% of total construction contract cost

HVAC and automated controls

1.5 to 4% of mechanical contract cost

Electrical system

1 to 1.5% of electrical contract cost

Figure 3: Actual Overall Commissioning Authority Costs as Percent of Construction

	Type of Building	State	Year Complete	Construction Cost	Mechanical	Electrical	Total M&E	Actual CA Fee	**Actual CA Fee % of M&E**	Comments
1	Mental Hospital	MT	96	$8,000,000	$2,000,000	NA	$2,000,000	$15,450	**0.8%**	Partial Cx Only
2	University Classroom	MT	97	$140,000	$140,000	$0	$140,000	$12,000	**8.6%**	VAV retrofit
3	University Classroom	MT	97	$14,000,000	$2,152,848	$1,514,562	$3,667,410	$45,600	**1.2%**	Partial Cx Only
4	University Lab/Classroom	MT	97	$14,400,000	$2,584,300	$1,409,100	$3,993,400	$73,800	**1.8%**	Partial Cx Only
5	Office	MT	97	$505,000	$420,000	$51,000	$471,000	$11,370	**2.4%**	Mechanical Replacement
6	University Lab/Classroom	MT	99	$6,500,000	$2,400,000	$805,000	$3,205,000	$49,907	**1.6%**	Mech/Elec Replacement
7	University Lab/Classroom	MT	99	$8,700,000	$2,763,500	$910,000	$3,673,500	$139,000	**3.8%**	Major Addition
8	Office	MT	98	$600,000	$227,000	$112,000	$339,000	$6,700	**2.0%**	Energy Retrofit
9	Lab/Classroom Addition	MT	99	$8,000,000	$1,473,797	$894,864	$2,368,661	$56,810	**2.4%**	In construction
10	Juvenile Detention	MT	99	$8,000,000	$1,570,241	$699,830	$2,270,071	$49,201	**2.2%**	In construction
11	Mental Hospital	MT	99	$12,000,000	$2,131,206	$1,440,994	$3,572,200	$110,600	**3.1%**	In construction
12	Office	MT	2001	$14,000,000	$4,965,000	$2,400,000	$7,365,000	$109,000	**1.5%**	In construction
13	Prison	MO	1998	$69,000,000	$13,800,000	$6,058,200	$19,858,200	$320,000	**1.6%**	In construction
14	Prison	MO	2001	$61,000,000	$12,200,000	$5,355,800	$17,555,800	$486,600	**2.8%**	In construction
15	Prison	MO	2001	$68,000,000	$13,600,000	$5,970,400	$19,570,400	$390,200	**2.0%**	In construction
16	Prison	MO	2001	$110,324,000	$22,064,800	$9,686,447	$31,751,247	$813,588	**2.6%**	In construction
17	Laboratory	MO	2000	$20,000,000	$6,500,000	$3,500,000	$10,000,000	$258,000	**2.6%**	In construction
18	Hospital	WA	2001	$6,746,000	$1,922,610	$785,076	$2,707,686	$63,000	**2.3%**	In construction
19	Student Union Building	WA	2001	$2,805,000	$883,575	$179,520	$1,063,095	$28,000	**2.6%**	In construction

Figure 4: Comparison of Actual Commissioning Costs to the 2.5%/1.5% Model

	Type of Building	Total Construction Cost	Mechanical	2.5% Mechanical	Electrical	1.5% Electrical	Total Model CA Fees	Actual CA Fee	Variation
1	Mental Hospital	$8,000,000	$2,000,000	$50,000	$0	$0	$50,000	$15,450	-69%
2	University Classroom	$140,000	$140,000	$3,500	$0	$0	$3,500	$12,000	243%
3	University Classroom	$14,000,000	$2,152,848	$53,821	$1,514,562	$22,718	$76,540	$45,600	-40%
4	University Lab/Classroom	$14,400,000	$2,584,300	$64,608	$1,409,100	$21,137	$85,744	$73,800	-14%
5	Office	$505,000	$420,000	$10,500	$51,000	$765	$11,265	$11,370	1%
6	University Lab/Classroom	$6,500,000	$2,400,000	$60,000	$805,000	$12,075	$72,075	$49,907	-31%
7	University Lab/Classroom	$8,700,000	$2,763,500	$69,088	$910,000	$13,650	$82,738	$139,000	68%
8	Office	$600,000	$227,000	$5,675	$112,000	$1,680	$7,355	$6,700	-9%
9	Lab/Classroom Addition	$8,000,000	$1,473,797	$36,845	$894,864	$13,423	$50,268	$56,810	13%
10	Juvenile Detention	$8,000,000	$1,570,241	$39,256	$699,830	$10,497	$49,753	$49,201	-1%
11	Mental Hospital	$12,000,000	$2,131,206	$53,280	$1,440,994	$21,615	$74,895	$110,600	48%
12	Office	$14,000,000	$4,965,000	$124,125	$2,400,000	$36,000	$160,125	$109,000	-32%
13	Prison	$69,000,000	$13,800,000	$345,000	$6,058,200	$90,873	$435,873	$320,000	-27%
14	Prison	$61,000,000	$12,200,000	$305,000	$5,355,800	$80,337	$385,337	$486,600	26%
15	Prison	$68,000,000	$13,600,000	$340,000	$5,970,400	$89,556	$429,556	$390,200	-9%
16	Prison	$110,324,000	$22,064,800	$551,620	$9,686,447	$145,297	$696,917	$773,880	11%
17	Laboratory	$20,000,000	$6,500,000	$162,500	$3,500,000	$52,500	$215,000	$258,000	20%
18	Hospital	$6,746,000	$1,922,610	$48,065	$785,076	$11,776	$59,841	$63,000	5%
19	Student Union Building	$2,805,000	$883,575	$22,089	$179,520	$2,693	$24,782	$28,000	13%

Figure 5: Actual Commissioning Contribution per SF

	Type of Building	Gross Floor Area	Actual Cx Authority Fee	
			Amount	Cost per SF
1	Mental Hospital		$15,450	
2	University Classroom		$12,000	
3	University Classroom	110,380	$45,600	$0.41
4	University Lab/Classroom		$73,800	
5	Office	32,268	$11,370	$0.35
6	University Lab/Classroom	44,966	$49,907	$1.11
7	University Lab/Classroom	140,700	$139,000	$0.99
8	Office		$6,700	
9	Lab/Classroom Addition	72,165	$56,810	$0.79
10	Juvenile Detention	45,915	$49,201	$1.07
11	Mental Hospital	79,130	$110,600	$1.40
12	Office	202,648	$109,000	$0.54
13	Prison	245,000	$320,000	$1.31
14	Prison	381,000	$486,600	$1.28
15	Prison	380,891	$390,200	$1.02
16	Prison	685,000	$773,880	$1.13
17	Laboratory	76,000	$258,000	$3.39
18	Hospital	51,000	$63,000	$1.24
19	Student Union Building	30,000	$28,000	$0.93

APPENDIX 6

Design Intent and Basis of Design

DESIGN INTENT DOCUMENT

This narrative is developed directly from the owner's program information. Will correspond to information provided to the state legislature and resulting legislative authorization. This narrative is prepared almost entirely by the project architect and contains "performance" criteria as opposed to design solutions (although tentative design solutions may need to be identified in the course of verifying the budget).

- Function of structure
- Location
- Utilities
- Life expectancy
- Level of quality
- Size and/or population
- Functional floor plan
- Environmental system requirements by area:
  - Temperature
  - Humidity
  - Fume Control
  - Particulates
  - Illumination
  - Noise
  - Vibration
  - Acoustics
  - O&M Access
- Energy efficiency
- Reliability of environmental systems-redundancy
- Emergency systems
- Life safety criteria
- Special design concerns
- Special O&M concerns
- Budget

COMMISSIONING/DESIGN NARRATIVE

for the AGRICULTURAL BIOSCIENCE FACILITY, at MONTANA STATE UNIVERSITY, BOZEMAN, MT

9/16/98

INTRODUCTION

This document is intended to fulfill two distinct functions. The first and primary function is to assist those responsible for commissioning of the building's mechanical systems and electrical systems in understanding the intended functions and acceptable performance limits of the facility's systems and equipment. The second and equally important intent is to readily provide an understandable description of the manner in which the building and its systems were intended to function for those who will be responsible for the maintenance and operation of the facility.

This document is not intended to describe the inherent operational characteristics of each piece or type of equipment installed within the facility. It is intended that those who use this document have at least a rudimentary understanding of modern HVAC and electrical equipment and that they have fully familiarized themselves with the project construction documents and the intended use of the building, its equipment and installed systems. It is believed that a greater benefit will result for those who use this document in close concert with the project plans and specifications and the operations & maintenance manuals provided by the contractor.

FACILITY DESCRIPTION

The Agricultural Bioscience Facility (ABF) at Montana State University was constructed as a dedicated research facility. As such, it is comprised almost solely of research labs, lab support areas and research office space. Although the facility houses a seminar room which can be used for various activities, the bulk of the building is dedicated to plant research activities and contains no classrooms or teaching labs. In addition to the construction of the new office and laboratory wings of the ABF, the project scope included limited renovation of, and additions to, the north end of the existing Plant Growth Center.

The Agricultural Bioscience Facility (ABF) is designed as a companion facility to the Plant Growth Center to the south. The PGC is a teaching and plant study/greenhouse facility for both students and faculty. As a pure research facility, the ABF augments the PGC with both field and academic plant research. The two facilities are linked by a connection corridor that allows scientists working in both buildings to easily move between them. The northeast corner of the PGC is comprised of a special containment area which is dedicated to the study of plants and plant related organisms (insects, plant bacteria, etc). The function of the containment area is directly related, in fact integral, to the research which will be carried on in the new ABF structure. As a portion of the ABF construction contract, limited remodeling and construction work was performed in the containment area of the PGC. Two new insect containment greenhouses were added, one existing insect containment greenhouse was converted to a plant pathogen containment greenhouse and a new 750 s.f. pathogen containment laboratory was constructed.

The functional program for ABF was "unbundled" into two distinct parts. This planning strategy allows the offices (30% of the building) to be constructed economically, allowing more labs to be built. The lab wing to the east consists solely of modular research labs and lab support areas (dark rooms, glass wash, cold rooms). The labs and the systems that serve them are planned to a strict module (720 sf) to make each space similar so flexibility, safety, future maintenance and first cost are significantly enhanced. The office wing is built to the west (forming a “T” in plan) with office support functions (seminar, facilities office) and research offices. The changes and additions to the PGC containment area allow for research to be conducted on an expanded spectrum.

MECHANICAL ROOM LOCATIONS

Each of the three building areas is served by one or more mechanical spaces. An attached key plan indicates the location of each of the main mechanical spaces in the facility. The PGC containment Greenhouses are served by a dedicated mechanical room which houses only air handlers and return/relief air fans which serve the greenhouses. The new pathogen containment laboratory in the PGC is also served by a new dedicated mechanical room. A ground floor mechanical room situated at the northwest side of the ABF office wing houses the primary chilled water pumps and a single air handler which serves the entire office wing. The lab wing of the ABF houses a total of three mechanical areas. The first is a central lower level mechanical room which connects directly to the campus utility tunnel system. This room houses the steam-to-water heat exchangers and the building heating water pumps and ancillary equipment. Directly above this room sits a “central” ground floor mechanical room which is located very near the intersection of the lab wing and the office wing of the ABF. This room houses a reverse osmosis (R-O) water purification system, a vacuum pump unit and an air compressor unit, all of which provide services to the laboratories of the “lab” wing. A separate small room located immediately adjacent to the ground floor central mechanical room houses the primary temperature control panels and contains a work desk and a control terminal for the temperature control system. The terminal employs full graphics for all of the facility controls. Finally, the attic space of the lab wing serves as a mechanical penthouse. It houses all of the primary air treatment equipment and the four air handlers which deliver air to the lab wing. It also contains the two primary fume hood exhaust system fans and various small exhaust fans which serve the lab wing.

CENTRAL SYSTEMS AND BUILDING UTILITIES

Although the separate portions of the building are largely served by separate mechanical systems, several central systems supply common heating and cooling utilities to all three of the building areas.

Campus steam is brought directly to the main lower level mechanical room and is the sole source of heat for the building. Hot water for building heating is produced by shell and tube heat exchangers. Some steam is also used directly to serve sterilizers in the lab wing and to produce pure steam from reverse osmosis water for humidification. The heating water pumps are located adjacent to the heat exchangers in the lower level central mechanical room. The heating system employs a single pumping loop (as opposed to primary/secondary pumping) in the building circulation system. Two pumps are provided and each is sized to produce nearly full capacity. Each of the pumps is controlled by a variable speed drive which increases pump speed in response to a pressure sensor in the supply water pipe loop. As the heating coil valves modulate open, the pump speed of the primary pump is increased to maintain a steady supply pressure. If, under peak demand conditions, one pump cannot keep up, the second pump will also start to provide extra pumping capacity. Upon failure of an active pump, the building temperature controls system senses pump failure and automatically switches to the other, stand-by, pump. Failure of one pump during peak loading conditions will leave the system with nearly full capacity pumping capability. The hot water circulation systems utilizes a mixture of 40% propylene glycol and 60% water to provide freeze protection at the coils, prevent system corrosion and deter boiling in the heat exchangers. Make-up solution for the system is automatically fed by a packaged make-up unit which is situated in the central first (ground) floor mechanical room.

Cooling water for the building's mechanical systems (chilled water coils in the air handlers) is produced by an outdoor air-cooled rotary (screw) chiller. The unit is located on the northeast side of the building by the loading dock. The pumping arrangement for the chilled water system is a primary/secondary (two pump) pumping loop. A chiller circulating pump (CCP-1) circulates water through the chiller evaporator barrel at a constant rate. The building circulation loop is fed by a floor mounted, variable speed pump. The building temperature control system adjusts the speed of this pump to maintain a constant pressure in the distribution system as the air handler chilled water coil valves modulate. This system also employs a glycol/water solution to prevent winter freezing in the chiller. It also employs a packaged make-up unit. The chilled water pumps and the make-up unit are all located in the ground floor office wing mechanical room. (Note: readers should be advised the project plans indicate that fully redundant pumps were to be provided for the chilled water system but were deleted by cost reduction measures at bid time. Pumps CWP-2 and CCP-2 were never installed. Operation is very similar to that of the heating system except that, in the event of a pump failure, there is no back-up capability.)

Natural gas is supplied to the facility by a small service line at the building's northwest corner. Gas is utilized for only two purposes: to supply small outlets in the laboratories for research purposes and to feed the emergency power generator. The power generator is located near the gas entrance, immediately adjacent to the PGC containment greenhouse mechanical room. Gas is not utilized by any building heating equipment or domestic water heaters.

OFFICE WING MECHANICAL SYSTEMS

The office wing is served by a large single air handler. This is the simplest air moving system employed in the facility. The air handler is situated in the office wing ground floor mechanical room and supplies air to all spaces within the three-floor office wing. This unit (AHU-1) is comprised of a filter/mixing box section, a heating coil section, a cooling coil section and a variable speed fan section. Air is distributed to pressure independent fan terminal units throughout this wing of the building. The variable speed drive controls the fan speed of the air handler to maintain a constant supply air pressure in the primary air ductwork at the most remote point of air distribution. The mixing box damper control strategy employs a minimum fresh air setting for most periods. As is normal for this region of the country, the building temperature control (TC) system increases the fresh air for the purpose of providing economizer cycle cooling. However, the amount of ventilation air admitted to the air handler is also increased by a carbon dioxide sensor located in the return air duct of the seminar room (room 108) in order to provide adequate ventilation during periods when this room is fully occupied for lengthy periods of time. With the air handler's fresh air damper positioned in the minimum setting, the mixed air temperature is suitable for distribution to the wing's fan terminal units even during periods of severe cold. However, when overridden by the carbon dioxide sensor for room 108, the volume of outside air admitted during inclement weather will drop below acceptable levels. In these instances the control valve for the air handler heating coil will modulate open to maintain a discharge air temperature which is suitable for distribution to the wing's fan terminal units. The cooling coil of the air handler functions in the same manner. The temperature of the air distributed to the fan terminal units must always be suitable for cooling of the office wing spaces. When the economizer function of the air handler will not maintain the minimum discharge temperature required, the cooling coil valve will modulate to provide the proper discharge air temperature.

Fan terminal units (FTU's) are situated throughout the office wing to maintain both suitable space temperatures and acceptable and comfortable levels of air circulation in each of the normally occupied spaces. With the exception of the rest rooms and several normally unoccupied spaces, all of this wing of the building is served by series flow (constant volume) fan terminal units. Large spaces, such as room 108, are served by more than one FTU. The bigger office spaces are served by dedicated (individual) FTU's and some of the smaller offices are grouped so that a single FTU serves two office spaces. The rest rooms and normally unoccupied spaces such as field storage room 110 are served by pressure independent variable air volume (VAV) boxes. All of the fan terminals and the VAV boxes are fitted with hydronic heating coils to maintain supply air temperature for heating.

The fresh air admitted for minimum ventilation purposes to this wing of the building is roughly the amount which is normally required as make-up air by the lab wing in order to maintain airflow <u>into</u> each laboratory. When the fresh air damper of AHU-1 is modulated open to provide increased ventilation in room 108 or to provide economizer cooling, the excess air admitted to the building is routed to the outdoors by three relief air dampers (and accompanying louvers), one of which is located at the northeast corner of each floor of the office wing. (Note: upon examining the project plans, readers should note that relief air fan RAF-1 and its three zone relief air dampers were deleted by cost reduction measures at bid time and were subsequently replaced by three relief damper/louver assemblies.) A building (zone) static pressure sensor is utilized on each floor of the office wing to monitor space static pressure and modulate its companion damper in order to maintain a slightly positive space static pressure. Because of the open arrangement of the ABF facility and its connection to the PGC building, it is anticipated that AHU-1 can be scheduled to be turned off at night without causing a shortage of make-up air to the lab wing. It is believed the make-up air required by the lab wing will be minimal enough that normal building leakage will be more than adequate for make-up purposes.

INSECT CONTAINMENT GREENHOUSE (PGC) MECHANICAL SYSTEMS

The air handling systems serving the newly added greenhouses in the PGC (greenhouses 162C and 162D) are of constant volume design and are simple in regard to design and operational strategy. However, because these units are called upon to maintain not only strict, but constant, pressure relationships with respect to the adjacent spaces, their control and function should be viewed with both a high degree of importance, if not complexity, than the systems which serve the office wing of the PGC. Each of the two greenhouses is served by a dedicated supply air handler and a companion return/relief air fan. The primary and most important function of each of these systems is to maintain their respective greenhouse at a static pressure which is negative to the adjacent non-greenhouse space(s). That is to say, regardless of heating or cooling demands, the airflow controls for these units must function to ensure that air flows <u>into</u> each greenhouse from adjacent spaces rather than flowing <u>from</u> a containment greenhouse to an adjacent space. This is accomplished by varying the volume of air which is exhausted to the building exterior with that which is returned to the air handler. The condition of negative air flow into the greenhouse must be maintained even under the conditions of a commercial power outage. The return/relief fans serving these spaces are connected to the emergency generator. During an outage of commercial power, the supply air handlers will cease operation, the return/relief fans will continue to operate under back-up power and the control dampers will modulate to maintain the space static pressure of each greenhouse at the predetermined set-point.

As mentioned above, each of these two systems is identical and is of a constant volume design. In this case, the “constant volume” aspect extends most specifically to the offset which must exist between the volume of supply air which is admitted to the space and the volume must be removed to the outdoors on a constant and continual basis in order to preserve the mandatory air flow orientations into the space. Although the supply air (air handler) and exhaust (return/relief) air fans operate at constant speed their delivery volume will necessarily change as the air handler and return air filters load with dirt and increase in resistance to air flow. Control dampers situated in both the supply air and return/relief air streams are employed to control the volumetric offset between supply air and the air which is relieved (exhausted) to the outdoors. The dampers respond on a continual basis to a space static pressure sensor and an outdoor (atmospheric) static pressure sensor in order to preserve air flow orientation into each greenhouse.

Under normal operating conditions (no loss in commercial power) each supply air handler and its companion return/relief air fan operate continuously, 24 hours per day, 365 days per year. In order to reduce complication and the risk of possible pressure control failure, the air handler mixing box dampers are fixed in position to admit a relatively constant amount of fresh air. As each air handler’s filters load with dirt and resistance to air flow increases, the amount of fresh air admitted will vary slightly. Each return/relief air fan also operates at constant speed to move a consistent amount of air. A set of modulating dampers located in the discharge duct of each return/relief fan is positioned by the building TC system to exhaust just enough air to maintain space static pressure.

Heating and cooling of the spaces is controlled by modulating the heating and cooling coil valves of the air handler. In order to provide a more uniform space temperature during extreme winter weather, each greenhouse is also served by a dedicated in-floor hydronic radiant heat tube system. The building TC system modulates the heating control valve and circulation pump associated with each of these systems in concert with the heating coil control valve for the respective air handler.

PGC PATHOGEN CONTAINMENT LAB MECHANICAL SYSTEMS

A new mechanical room was constructed in this addition to house a single air handler dedicated to serving only the new lab and the upgraded greenhouse. The air handler includes both a supply fan and a return/relief air fan and operates at a constant volume with a fixed amount of fresh air intake. Unlike the air handlers which serve the new insect containment greenhouses, this unit is a multi-zone air handler. The containment laboratory comprises one zone and the greenhouse constitutes the second zone. Because the pathogens which are under study must be contained to these spaces, a number of design considerations are employed. Both fans of the air handler must operate continuously, even during a power outage. Emergency power for the unit is derived from the new emergency generator. Both the supply and return/exhaust air streams are fitted with redundant side-by-side HEPA filters. Insect screens cover both the intake and relief air openings at the building perimeter. Aside from the air handling unit being of the multi-zone design, the controls and the heating and cooling functions for this unit are the same as for the insect containment greenhouses. Here, as in the other greenhouses, space pressure control is the most important aspect of system performance. Unlike the insect greenhouse systems, both the supply and exhaust fans are connected to emergency power.

LABORATORY WING MECHANICAL SYSTEMS

Although they are conceptually simple, the HVAC systems which serve the lab wing are probably the most complex in the facility. This is because they combine the need for stringent directional airflow control into each laboratory (similar to the containment greenhouses) with variable air volume control. They further combine the building temperature control system with individual digital airflow control systems in each laboratory. However, several features of the systems help to reduce the level of complexity. The bulk of the systems and equipment are repetative in nature, both in terms of equipment design and in terms of equipment functions (control sequences).

The HVAC systems in this wing of the building are primarily of the "once-through" type because building and fire codes prohibit recirculation of air in laboratory facilities. As such, the vast majority of the air which is admitted to the lab wing (and all of the air which is admitted to the laboratories) is directly exhausted to the outdoors. Because of obvious energy consumption considerations for such systems, it is desirable to minimize the air delivered to the labs any time they are not in use or have no large heating and cooling loads. The systems which serve the laboratories must operate continuously, only ceasing operation in the event of a commercial power outage.

The major air moving components for both the exhaust and supply air systems in this wing are located in the attic "penthouse" mechanical room. The supply air system is comprised of four air handlers and a common fresh air conditioning plenum (FACP) assembly. The FACP "pre-conditions" all of the fresh air admitted to the four air handlers by filtering it (30% pre-filters), pre-heating it to 55°F when necessary and then humidifying the air stream to a humidity level which is equivalent to 20-25% RH at 70°F (a dew point of approximately 33°F). The air which leaves the FACP is then ducted to four variable air volume air handlers.

Three of the air handling units are dedicated to serving only laboratory spaces with each unit being dedicated to serve the lab spaces on each of the three floor levels. That is to say one unit serves the first floor lab spaces, one unit serves the second floor labs and one is dedicated to the third floor labs. Each of these units is comprised simply of a high efficiency (85%) bag filter section (no return air), a cooling coil section and a variable speed fan section. Fan speed is controlled by a duct static pressure sensor to maintain a steady supply pressure at the laboratory terminal units. The cooling coil chilled water control valve for each unit modulates to maintain set-point conditions for space cooling.

The fourth air handler in the mechanical penthouse serves the non-laboratory spaces on all three floors of lab wing. This unit is similar in design to air handler AHU-1 of the office wing in that it utilizes some return air and is comprised of a mixing box, a cooling coil and a variable speed fan. Because this unit recirculates air from the non-laboratory spaces, it is the "exception" to the once-through air flow patterns of the lab wing. It is similar to the other three air handlers in the penthouse in that there is no heating coil. This unit supplies air to conventional FTU's and VAV boxes in the lab wing which are identical in design to those installed in the office wing.

The distribution of air to each laboratory is controlled by three terminal devices, one for supply air and two for exhaust. All are pressure independent venturi air valves manufactured by Phoenix. The supply air valve is fitted with a hydronic booster heating coil and delivers all of its air to the lab space. Ceiling slot diffusers are used near window spaces to deter drafts and avert window frosting in cold weather. Perforated ceiling diffusers are employed in the center of each room to minimize stray air currents which could interfere with proper airflow into the fume hoods. The exhaust air system is comprised of one air valve which is directly connected to the fume hood discharge duct and one which pulls general exhaust from the room through ceiling grilles. All of the three air valves are of a variable air volume design with pneumatic actuators. A dedicated airflow control system which is supplied by the air valve manufacturer (Phoenix) controls the position of each valve. These controls provide three very important functions. The first of these is to exhaust more air from each lab than is supplied (no matter how much air is supplied). The target volumetric offset to each laboratory is approximately 100 cfm with a tolerance in the range of 10 cfm to 190 cfm. This ensures the lab will never “go positive” to the adjacent corridor and will contain all chemical fumes to the lab. The second function of the controls is to increase the rate of exhaust drawn from the fume hood as the sash is raised in order to maintain a uniform entry velocity of 100 feet per minute through the sash opening. This is accomplished by a sash positioning sensor at each hood (the sensor is also supplied by Phoenix). As the total exhaust volume increases, the supply air volume is increased to maintain the room volumetric offset. The third function of the air flow control system is to increase both the supply and exhaust rates from their minimum volumes in order to maintain space temperature set point in the lab. If, for example, more cooling air is needed, the supply air valve will modulate open and the general room exhaust valve will track with it. Again, the positions of the valves are monitored to ensure that the volumetric offset into the room is preserved at all times. A more complete description of the operation of these systems is included on the temperature control sheets of the project plans.

The exhaust duct systems which serve the laboratory spaces are constructed of welded stainless steel as a precaution against acidic or caustic induced corrosion. These ducts route vertically to the penthouse mechanical room where they are joined into a common main. The exhaust ductwork exposed in the penthouse is constructed of galvanized steel rather than stainless steel. It is believed that any fumes which would cause excessive corrosion will be extensively diluted by this point, and that if a duct were to corrode several years from now, there is adequate access to accomplish replacement. The main exhaust duct is then routed to two large stainless steel constructed fume exhaust fans at the north end of the penthouse. These fans are variable speed driven and are controlled to maintain a negative pressure set-point in the ductwork. If one fan cannot maintain the required set-point, the other will start and the two will ramp together.

Rather than sizing the large fume exhaust fans to handle the full connected load, a number of factors were weighed in the calculations for this system. The exhaust rate from the laboratories is dependant upon three factors. The first of these is code driven. Building codes require that a minimum of six air changes per hour (AC/hr) be maintained at all times in laboratories of this type. This is enough air for all the fume hoods in the facility to function with their sash partially open. It is also enough airflow to provide adequate heating and cooling during all but the most extreme weather conditions. The terminal equipment and ductwork serving each lab are sized to allow the fume hood to operate with a face velocity of 100 feet per minute with the hood sash fully open. However,this equates to more than 12 AC/hr in most spaces. Because it is highly unlikely that all fume hoods will ever concurrently operate with a fully open sash, a modest amount of diversity was allowed in sizing of the exhaust fans. A lesser amount of diversity was allowed in sizing the supply air handlers which serve each floor.

DESIGN CRITERIA

The outdoor design conditions for the facility are as follows:

Summer: 90°F dry bulb / 61°F wet bulb
Winter: -20°F

The indoor design conditions for the various areas of the building are as follows:

General Office:	78°F cooling/72°F heating ±2°F
Public Areas:	78°F cooling/72°F heating ±2°F
Laboratories:	72? to 75°F ±2°F constant, 20% to 30% RH
Greenhouses:	72? to 75°F ±2°F constant
Ventilation:	20 cfm per person or greater as dictated by exhaust systems
Filtration:	Office and public areas: 30%
	Laboratories and greenhouses: 85%
Airflow:	Office Areas: No required orientation
	Laboratories: 100 cfm inward to each lab ±90 cfm
	Greenhouses: 0.05" w.c. negative ±0.03" relative to adjacent space
Balancing:	As scheduled ±10% for total airflow as outlined in NEBB standards

CRITICAL PERFORMANCE CRITERIA

All of the HVAC equipment should perform as described on the project plan schedules with regards to capacities, pressure drops, etc. While the precise performance of every piece of equipment may not be crucial to proper operation of the facility, there are several items whose performance is vital. Central heating and cooling equipment, for example must be able to meet their intended performance so that building temperatures can be maintained. Also, control sequences which are critical to the maintenance of precise pressure relationships must perform properly. The commissioning process will establish that critical equipment and systems perform properly when the building is turned over to the owner. Carefully planned and executed maintenance programs will help ensure that the systems and equipment continue to function as intended over time.

Below is a list of equipment and/or systems whose functions are of a critical nature. It is provided only as a supplement to the commissioning specifications for this project which already outline specific testing and procedural requirements.

1. The performance of heating and chilled water pumps and verification of the concentration of glycol in these systems. The pumps should be demonstrated to be operating upon their intended curve at scheduled conditions. The concentration of glycol in the pumping systems impacts not only pressure drop throughout the system but heat transfer as well. A concentration of 40% propylene glycol, 60% water is specified for both systems. This concentration equates to a freezing point (not to be confused with burst protection) of -10°F and is testable with the refractometer which the contractor is to supply the owner. The balancing and testing of the chilled water system should take place only with the system operating at design temperatures to ensure that system pressure drops, as affected by viscosity, are consistent with actual operating conditions.

2. The chiller performance should be tested against its rated capacity once the system flow rates are properly balanced. The leaving chilled water temperature should also be monitored to ensure that it continually maintains set-point conditions of 44°F±2°F. Excessive deviations from the set-point can potentially cause a cascade of system "hunting", not only for coil control valves, but also for the variable air volume control valves in the laboratories.
3. The capacities of the heating water convertors should be verified to ensure that even in the event of failure of one unit, the other will be capable of maintaining tolerable building conditions.
4. The capacity of the fresh air pre-heat coils in the lab wing penthouse fresh air conditioning plenum should be capacity tested to ensure enough heating will be available at design air flow rates during extreme weather.
5. The capacities of the air handler heating and cooling coils should be verified.
6. The capacity and control functions of the fume exhaust fans in the lab wing penthouse should be verified. This includes the ability to maintain duct static pressure levels within tolerable limits during a fan failure scenario, during scheduled switch-over of the lead and lag fans and during routine fan cut-in / cut-out operation in response to system loading. The ramping speeds of the drives for these units should be demonstrated and adjusted as necessary to ensure tolerable limits are not exceeded.
7. The capacity and control of the PCG containment area air handlers should be verified under various filter loading conditions and during simulated power outages. A more complete description of this testing is listed on the revised greenhouse plans issued July 8, 1998 by Gordon-Prill-Drapes. This testing includes the function of the pressure control system and the dampers which control space pressurization, even during power outages.
8. All of the laboratory airflow control systems should be verified to operate properly under heating and cooling loads and for various sash positions at the fume hood. The face velocity of air entering the fume hood should be checked to ensure that 100 fpm ±10 fpm is maintained at all sash positions and that the throw patterns from the supply air diffusers in each lab are not interfering with proper sash velocity profiles. Observations should be made during these procedures to ensure airflow offset is maintained and is oriented into each lab.
9. The performance and capacity of terminal unit hydronic booster coils (reheat coils) should be spot checked to ensure adequate coil capacity for winter heating.
10. The function of the emergency generator should be verified under conditions in which all normal building systems are operating. That is to say all air handlers, etc. which receive emergency power are operational at the time of the test.
11. The function of the fire alarm system should be verified as outlined in specifications. Specific regard should be paid to the reset functions which enable mechanical equipment to restart following an alarm event.

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BASIS OF DESIGN DOCUMENT

Follows directly from the Design Intent Document and identifies technical and operational methods of satisfying the design intent. Includes:

- Weather conditions

- System selection
  - HVAC
  - Utility systems
  - Lighting
  - Life safety
  - Emergency
  - Code requirements
  - Owner requirements
  - Industry requirements

- Confirmation of Feasibility
  - Temperature
  - Humidity
  - Particulates
  - Noise
  - Vibration
  - Lighting
  - Budget

- Special Systems
  - Pure water
  - Lab gas
  - Fume control
  - Pressurization

PINE HILLS JUVENILE CORRECTION FACILITY EXPANSION/CONSOLIDATION--BASIS OF DESIGN

I. MECHANICAL REASONING AND LOGIC

A. HVAC SYSTEM SELECTION

1. Central Heating Plant

The Pine Hills Campus will be consolidated under this project. The buildings on the north side will be either abandoned and/or sold to independent parties. The buildings on the southern half of the Campus will be reutilized and augmented by a new administrative and housing facility. At the present time, there is a central steam plant which serves all buildings north and south on the Campus. A system of underground tunnels with steam and condensate piping distributes the heat from the boiler plant to each building. The boilers appear to be approximately 35 years old. The boilers are combination natural gas and fuel oil; however, problems have been experienced with the fuel oil portion, and this area requires additional work if these boilers were to remain. It was determined during initial programming that a new central heating plant dedicated to the consolidated Campus would best meet the long term needs of the Campus and allow for the northern half to be isolated and/or totally deenergized if so desired.

A new central heating plant will be developed in the existing shop building. This building is ideal, in that it has adequate floor space and height, is centrally located and is also outside the security perimeter The boilers chosen for this project are multiple, flexible water tube type similar to those manufactured by Cleaver Brooks. We have utilized these boilers successfully on numerous projects over the years. The use of multiple boilers will allow for backup capability and on-going maintenance without severe disruption to the Campus. A benefit of utilizing the flexible tube boilers is that, due to their small footprint, the boilers can be easily installed in the existing shop building without extensive modification to the building structure or the addition of additional overhead doors, etc.

New hot water piping will be routed from the new boiler plant to the existing north/south tunnel. The existing steam and condensate piping will be reutilized at this point. The buildings served by this new boiler plant will include the following:

Shop Building
Range Rider Lodge
The School
The Gymnasium
The new Housing/Administrative Facility

The gym, the school, and the new administrative/housing facility all have hydronic heating systems at the present time. It will be necessary in the Range Rider to convert the heating coil in the air handler to a hot water style. In the shop building, it will be necessary to convert the unit heaters from steam to hot water.

2. Central Chilled Water Plant

The new administrative/housing facility will require air conditioning. The other existing building's cooling will remain as is under this project. A new central chilled water plant dedicated to the administrative/housing facility will be provided. An air cooled chiller is the most cost effective for this application. The intent is to locate the central chiller adjacent to the new heating plant, which puts it in close proximity to the central electrical service. This will minimize the electrical conduit and wiring runs to this piece of equipment, which is typically one of the larger mechanical loads for the electrical systems. Water will be distributed from the central chilled water plant to the administrative/housing facility through the tunnel system.

3. Air Distribution

a. Administrative/Housing Wing

New air handling units will be provided for each of the areas in the administrative/ housing facility. Each air handling unit will have both chilled water cooling and hot water heating capability. The housing units have an extensive amount of exhaust and corresponding make-up air. The decision was made during preliminary design and confirmed during value engineering that the most appropriate system for these housing wings would be to provide a dedicated air handling unit with an air-to-air heat recovery capability. This would allow the facility to bring in the required amount of ventilation and recover heat from the exhaust air. Due to the limited glazing in the facility, the solar effect is minimal. It was decided and again confirmed during value engineering that a constant volume system for these housing units would prove to be the most cost effective with heating coils installed in each zone to provide approximately 5 to 6 zones of control per housing unit. Each housing unit will have its own dedicated air handling unit. This will allow for smoke control to be accomplished in a fairly cost effective and simple manner.

b. Administrative Wing

This wing will be provided with a Variable Air Volume system. The system is a single duct type with VAV boxes with terminal heating. The building will be zoned as shown on the drawings with 2 to 3 offices grouped on a common thermostat. Corner offices will be on their own thermostat.

c. Kitchen

The kitchen area has a high degree of make-up air required to offset the exhaust from the central kitchen hood, as well as the dishwasher hood. A direct fired make-up air unit with evaporative cooling was chosen for this area. This was felt to be the most cost effective and energy efficient method of providing a suitable working environment in this area. By utilizing the evaporative cooling in lieu of a chilled water coil, significant load was taken off of the chiller and made available for future expansion of the facility. The make-up air unit will be interlocked with the kitchen hoods so as to be energized only when the hoods are in use.

d. Intake

The intake of the area of the facility is similar in many respects to the housing area on a much smaller basis. It was not felt cost effective to install heat recovery in the intake area due to the much reduced air volumes. A constant volume air handling unit with zone heating coils is to be provided for this area. Outside area air to offset that exhausted will be provided through this make-up air unit.

e. Temperature Controls

The Pine Hills Campus has implemented some energy conservation upgrades over the last several years. At the present time, there is a Johnson Metasys System installed in the Administration Building which monitors several of the buildings on the Campus. We have been in contact with Johnson Controls and the central panel is definitely reusable. The intent is to relocate it to the new heating plant and make this the central point for temperature controls for the consolidated Campus. New electronic controls will be installed in the administration/housing building. Controls in the rest of the Campus will remain essentially as is.

II. DESIGN PARAMETERS

A. TEMPERATURES

Indoor	Summer	Winter
Administration	75°F	72°F
Housing	75°F	72°F
Maintenance/Storage/Utility	N/A	60°F
Kitchen	78°F	68°F
Outdoor db/wb	97/66°F	-19°F

B. ELEVATION 2628 Ft.

C. INDOOR TEMPERATURE SWING TOLERANCE

Housing Pod	± 2°F
Administration	± 2°F
Kitchen	± 5°F
Intake	± 2°F
Maintenance	± 5°F (heat only)

D. VENTILATION REQUIREMENTS

Housing	20 cfm/person
Administration	20 cfm/person

E. ROOM OCCUPANCY

Housing Pods	1 person/cell
Administration	7 person/1,000 s.f.
Conference/Meeting Room	50 persons/1,000 s.f.

F. ROOM OCCUPANCY

Housing Pods	24 hrs. per day
Intake	24 hrs. per day
Administration	7:00 a.m. - 6:00 p.m.
Kitchen	6:00 a.m. - 7:00 p.m.

Included courtesy of
Associated Construction Engineering, Inc., Belgrade, MT

Figure 6: Guiding Documents for the Commissioning Process

Document	Stage of Commissioning	Done By
Design Intent Narrative	Pre-Design	Consulting Architect/Planning Team
Owner's Commissioning Procedure	Pre-Design/Early Design	Owner's Project manager
Preliminary Commissioning Plan	Design Specifications	Commissioning Authority
Detailed Commissioning Plan	Early Construction	Commissioning Authority
Inspection and Functional Performance Test Forms	Acceptance	Commissioning Authority
Commissioning Report	Completion	Commissioning Authority

APPENDIX 7

Schedules and Tracking Documents

Item 1

Preliminary Functional Testing Schedule June 1998

Chemistry Building Renovation
Montana Tech
Montana A/E 95-06-02

HVAC Systems:

Item/System	Week 1	Week 2	Week 3	Week 4
1. Chilled water piping system glycol feeder	X			
2. Heating water piping system glycol feeder	X			
3. Heat recovery piping system glycol feeder	X			
4. CH-1 and chilled water pumps P-3, P-4	X			
5. Packaged heat transfer unit, including pumps P-1 and P-2	X			
6. Condensate pump CP-1	X			
7. Miscellaneous systems				
A. Horizontal unit heaters UH-3, UH-4 (4 total)	X			
B. Cabinet unit heaters UH-1, UH-2 (3 total)	X			
C. Fan-coil unit FC-8	X			
D. Exhaust fan EF-5	X			
E. Exhaust fan EF-6	X			
8. Air handlers, associated exhaust fans, and associated heat recovery system and pump				
A. Basement System	X			
B. First Floor System	X			
C. Second Floor System		X		
D. Third Floor System		X		
9. Supply and exhuast VAV terminals, and associated fan-coils and fume hoods				
A. Basement Systems				
1. Rm 001: S0-4, S0-5, E0-3, H0-1 to H0-6		X		
2. Rm 002: S0-7, H0-7, H0-8		X		
3. Rm 014: S0-10, S0-11, E0-6, E0-7, H0-9		X		
4. Rm 015: S0-12, S0-13, E0-8, E0-9, H0-10		X		
5. Rm 005: S0-14, E0-10		X		
6. Rm 009: S0-3, E0-1		X		
7. Rm 016: S0-1, E0-11, FC-7		X		
B. First Floor Systems				
1. Rm 101: S1-7, S1-8, E1-1, H1-3		X		
2. Rm 108: S1-4, H1-5, H1-6		X		
3. Rm 1091: S1-2, E1-8, H1-8		X		
4. Rm 111: S1-12, E1-5, H1-1		X		
5. Rm 107: S1-5, E1-3		X		
6. Rm 115: S1-10, E1-6		X		
7. Rm 117: S1-9, E1-7		X		

HVAC Systems (Cont'd):

Item/System	Week 1	Week 2	Week 3	Week 4
C. Second Floor Systems				
1. Rm 205: S2-13, H2-5, H2-6		X		
2. Rm 206: S2-3, H2-3, H2-4, H2-9, EF-4, perchloric hood washdown		X		
3. Rm 207: S2-2, E2-4, H2-7, FC-5, FC-6			X	
4. Rm 226: S2-10, S2-11, E2-1, E2-2, H2-1, H2-2			X	
5. Rm 227: S2-17, E2-11, H2-8			X	
6. Rms 208/210/211/212: S2-5, E2-7			X	
7. Rm 213: S2-16, E2-8			X	
8. Rm 219/220/221: S2-15, E2-8			X	
D. Third Floor Systems				
1. Rm 301: S3-5, E3-6, E3-7, H3-4, FC-1, FC-2, FC-3			X	
2. Rm 302: S3-1, E3-4, H3-1, H3-2, H3-3			X	
3. Rm 312: S3-3, E3-3, H3-5, H3-6			X	
4. Rm 305: S3-6, E3-8, E3-9, FC-4			X	
5. Rm 306: S3-4, E3-1			X	
10. Building automation system			X	

Plumbing and Laboratory Systems:

Item/System	Week 1	Week 2	Week 3	Week 4
1. Domestic water system				X
2. Compressed air piping				X
3. De-ionized water system				X
4. Lab natural gas piping				X

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Item 2

Project: University of Montana Pharmacy/Psychology Building Addition

Task / Activity	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	1999											
Fire Protection Systems (17300)												
Pressure Test		■										
Inspection/Start-up										■		
Domestic Water, Waste, and Vent Systems (17400)												
Underground Pressure Test												
Pressure Test			■	■	■							
Flushing					■							
Sewage/Sump Pump Start-up										■		
Laboratory Systems (17420)												
Pressure Test				■	■							
Flushing										■		
Independent Testing/Start-up											■	
Natural Gas Systems (17430)												
Pressure Test				■	■							
Start-up										■		
Heating Hot Water Systems (17500)												
Pressure Test		■	■									
Flushing			■									
Start-up										■		
TAB											■	
FPT											■	■
Steam and Condensate Systems (17510)												
Pressure Test (N/A)												
Flushing (N/A)												
Start-up (N/A)												
FPT (N/A)												
Heat Recovery Systems (17520)												
Pressure Test			■									
Flushing			■									
Start-up										■		
TAB											■	
FPT											■	■
Ground Water and Chilled Water Systems (17530)												
Pressure Test		■	■									
Flushing			■									
Start-up										■		
TAB											■	
FPT											■	■
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	1999											

NOTES:
1. This schedule is preliminary and will be updated as required as construction and commissioning progresses.
2. The time line is not necessarily intended to indicate the specific duration of each task, but rather the general time frame in which the task will be performed.

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Item 3

College Center Building Commissioning

Contractor Support Requirements

Start-up and Functional Performance Testing for:	Speedy Controls Company	Hot Shot Electrical Contractors	Sharp Edge Sheet Metal	No-Drip Plumbing and Heating
Air Handling Unit 1 and Variable Frequency Drive	X	X + VFD Rep	X + AHU Rep	X
Air Handling Unit 2 and Variable Frequency Drive	X	X + VFD Rep	X + AHU Rep	X
Air Handling Unit 3 and Variable Frequency Drive	X	X + VFD Rep	X + AHU Rep	X
Air Handling Unit 4 and Variable Frequency Drive	X	X + VFD Rep	X + AHU Rep	X
Chilled Water Pump CWP-1 and VFD	X	X + VFD Rep		X + Pump Rep
Chilled Water Pump CWP-2 and VFD	X	X + VFD Rep		X + Pump Rep
Chiller ACC-1	X + Chiller Rep	X		X
Chiller ACC-2	X + Chiller Rep	X		X
Chiller Circulating Pump CCP-1		X		X + Pump Rep
Chiller Circulating Pump CCP-2		X		X + Pump Rep
Garage AHU-1	X	X	X + AHU Rep	X
Garage AHU-2	X	X	X + AHU Rep	X
Heating Water Pump HWP-1 and VFD	X	X		X + Pump Rep
Heating Water Pump HWP-2 and VFD	X	X		X + Pump Rep
Heat Water Steam Converter HWC-1	X + Rep			X + Converter Rep
Sump Pump SP-1		X		X + Pump Rep
BAS Graphical User Interface	X + Rep			

Notes:

"X" indicates one journeyman level company representative is required. Others may be present at contractor's option. "Rep" indicates that factory representative is required for testing and/or start-up to proceed.

Item 4

LOOK AHEAD SCHEDULE NO. 3

Agricultural Bioscience Facility
Montana State University

TEST NO.	TEST DESCRIPTION	DATE	TIME	MEETING LOCATION	CONTRACTOR	COMMENTS
HWFC	Heating Water System Flush/Clean	Complete**				
SCFC	Steam/Condensate Flush/Clean	Complete**				
HWS1	Heating Water Pumps Start-Up	Complete				
VFD	HWP Variable Frequency Drive Start-Up	Complete**			Matzinger	Need VFD Data
SAS2	AHU-2 Start-Up and VFD	Complete**			Matzinger	Need VFD Data
SAS2	AHU-3 Start-Up and VFD	Complete**			Matzinger	Need VFD Data
SAS2	AHU-4 Start-Up and VFD	Complete**			Matzinger	Need VFD Data
SAS5	AHU-5 Start-Up and VFD	Complete**			Matzinger	Need VFD Data
SAS1	AHU-1 Start-Up and VFD	Complete**			Matzinger	Need VFD Data
EAS1	Lab Exhaust Fans FEF-1/2 Start-Up	Complete**			Matzinger	Need VFD Data
CWS1	Chiller Circ Pump CCP-1 Start-Up	Complete				
CWS2	Chilled Water Pump CWP-1 Start-Up	Complete**			Matzinger	Need VFD Data
CWS3	Chiller ACC-1 Start-Up	11/16/98	8:00 am to 4:00 pm	Yard	Williams/Johnson	
PSS1	Domestic Hot Water Pump Start-Up	11/17/98	8:00 am to 9:00 am	Mech Room	Williams	
PSFC	Domestic Water Systems Flush/Clean	11/17/98	2 days	Mech Room	Williams	
PSS2	Steam Water Heater WH-1 Start-Up	11/19/98	9:00 am to 11:00 am	Mech Room	Williams/Johnson	
PSS3	Sump Pump SP-1 Start-Up	11/19/98	1:00 pm to 2:30 pm	Mech Room	Williams/Johnson	
	Phoenix Valve Factory Rep On-Site	11/30/98	All week	Lab Wing	Johnson	
TAB	Start T/A/B	11/30/98	All week and more	Lab Wing	RGO / MOM	
ES01	FPT Emergency Generator	12/08/98	8:00 am to 4:00 pm	Generator	Matzinger	Factory Rep
ES02	Generator Main Breaker	12/08/98	8:00 am to 4:00 pm	Generator	Matzinger	Factory Rep
ES03	Automatic Transfer Switches	12/09/98	8:00 am to 4:00 pm	Generator	Matzinger	Factory Rep

** = This test is complete with deficiencies. The deficiencies must be corrected before the system will be accepted.

No changes allowed to this schedule with 3 days prior notice.
Contractors are responsible to ensure the systems to be tested are ready to be witnessed.

Prepared by Gerald Ensminger
Courtesy of Testcom, Inc. of Spokane, Washington

Item 5

SYSTEM/EQUIPMENT DISCREPANCY SUMMARY

Project: **U of M Pharmacy/Psychology Addition** Building: **North Addition**
By: **Facility Improvement Corporation** System: **AHU-1/RAF-1/VAU-1/EF-1**

Item #	Test Procedure	Discrepancy Description	Recommended Action	Suggested esponsibility	Status	Fix √
AHU1-1	AHU-1, VAU-1 Start-up	Spare filters are specified.	Deliver a spare set of HREF-2 and AHU-4 filters to UM.	SM	Spare filters ordered 1-12-20	
AHU1-2	RAF-1 Start-Up	RAF-1 will not operate when VFD is switched into bypass. The distribution panel circuit breaker trips.	Check distribution panel circuit breaker sizing. Replace circuit breaker as required.	EE, EC	Done	√
AHU1-3	MI-1-AHU-1/RAF-1	AHU-1 supply ductwork in 1st Floor chase is not insulated.	Complete insulation installation per specifications.	MC	Done	√
AHU1-4	MI-1-AHU-1/RAF-1	There is a tear in AHU-1 supply ductwork insulation in the North Penthouse	Repair duct insulation.	MC	Scheduled for wk of 1-24-00	
AHU1-5	MI-1-AHU-1/RAF-1	AHU-1 condensate drain is not trapped and piped to drain.	Provide condensate drain trap as shown on the drawings	MC	Done	√
AHU1-6	MI-1-AHU-1/RAF-1	Holes were drilled in AHU-1 housing to route cables for airflow meter. This routing was abandoned.	Caulk/plug abandoned holes to prevent air leakage.	SM	Done	√
AHU1-7	MI-1-AHU-1/RAF-1	Cables for airflow meter are not protected from cut edge of AHU-1 housing.	Provide grommet or protect cable using pneumatic tubing. Caulk/ plug holes to prevent air leakage.	SM	Not Done	
AHU1-8	MI-1-AHU-1/RAF-1	AHU-1 fan belts are loose.	Tighten fan belts per the manu-facturer's recommendations. Verify tightness with a belt tension gage.	SM	FICO will inspect w/SM week of 1-17 to check tightness	
AHU1-9	MI-1-AHU-1/RAF-1	AHU-1 outside air damper is not installed properly.	Install additional fasteners to secure outside air dampers. Caulk around dampers to reduce leakage.	SM	Done	√

ARCH	Architect	FA	Fire Alarm	ME	Mechanical Engineer
Cx	Commissioning Agent	FP	Fire Protection	SM	Sheet Metal Contractor
EC	Electrical Contractor	GC	General Contractor	TC	Temperature Control Contractor
EE	Electrical Engineer	MC	Mechanical Contractor	UM	University of Montana

Courtesy of
Facility Improvement Corporation, Great Falls, MT

Item 6

EMPIRE STATE BUILDING
TESTING STATUS

Test Number	Description of Test	Not Yet Tested	Tested Correction Required	Tested No Deficiencies
PU01	HW Circ Pump 1			xxxxx
PU02	HW Circ Pump 2			xxxxx
PU03	Condenser Water Pump 1		xxxxx	
SAS1	AHU 1			xxxxx
SAS2	AHU 2		xxxxx	
SAS3	AHU 3		xxxxx	
SAS4	AHU 4		xxxxx	
CON1	Temperature Sensors	xxxxx		
CON2	Humidity Sensors	xxxxx		
CON3	Control Air Piping	xxxxx		
CON4	Control Air Compressor			
RO1	Reverse Osmosis Water Piping	xxxxx		
RO2	RO Generator	xxxxx		

APPENDIX 8

Problems Found and Corrected

Discrepancies - Air Handling Units

System	Sub-System	Test	Deficiency
Air Handling Units	Air Side	Start-up, mech	Portions of return-air path blocked by walls
			Poor/no filter sealing
			No filter changing access
			Insufficient condensate pan drain slope
			Mixing dampers block control damper operation
			Spare filters not supplied
			Existing filters very dirty
			Vibration isolators missing/incompletely anchored
			Condensate drain not trapped
			Sheet metal joints are skewed and leaky
			Fan/motor sheaves not aligned--belts loose
			AHU not bolted down
			Suspended AHU not earthquake braced
			No filter changing pull strip
			Fan wheel wobbly---out of alignment
		Start-up, elec	AHU conduit penetration into AHU unsealed
			No flex connection for conduit at AHU
			Motor overloads incorrectly set
			Motor trips out on starting
			Motor starters not labeled
			Disconnect cover plate missing
		Start-up, controls	AHUs will not shut down on safety freeze 'stat
			EMCS sensors missing
			EMCS sensors incorrectly located
			EMCS sensor penetrations unsealed
			Wrong face and bypass switch point
			Lack of panel documentation
			High pressure limit switch not labeled
			Damper linkage disconnected
			Damper actuator insufficient size to close dampers
			Damper too small for ductwork, air leaks around
			Access door jammed, cannot be opened for maintenance
		FPT	AHUs operating in parallel cannot supply req'd flow
			Nuisance freeze 'stat trips due to flow imbalance
			Nuisance freeze 'stat trips due to air stratification
			Dampers fail to cold deck instead of hot deck
			Freeze 'stat operates in AHU "auto" mode only
			AHU can collapse ductwork if return fan fails
			Back-rotating return fan trips on start-up
			Back-rotating exhaust fan trips on start-up
	Ductwork	Inspection	Ductwork insulation missing
			Seals missing--ducts leak
			Fire damper link broken-damper closed
			Fire damper improperly sealed
			Fire damper installed upside down

Discrepancies - Air Handling Units

System	Sub-System	Test	Deficiency
Air Handling Units	Ductwork	Inspection	Fire damper location not marked on ceiling tile
			Balancing damper has no handle
			Balancing damper has no locking quadrant
	Relief dampers	Inspection	Damper not sealed to frame
			Frame not sealed to wall
		FPT	Dampers stick and bind--frames twisted
			Backflow through relief dampers due to exhaust fans
			Rain and snow enter exhaust louver when fan is off
			No bird screen on exhaust louver
	Exhaust fans	Start-up, controls	Duct static pressure sensor incorrectly located
			Two exhaust/Relief fans are switched relative to AHUs--result is no pressure control in two spaces
	Return fans	Start-up, controls	Fan overloaded, motor trips out
Humidifiers	Piping	Inspection	Drain line plugged
			Drain line insufficient slope
			No union in drain line for maintenance
			Insufficient piping support
	Ductwork	Inspection	Insufficient downstream straight duct for mixing
		FPTs	Humidifier lacks control-cycles full on/off
			Not able to reach desired humidity set-point
Unitary Equipment	Unit heaters	Inspection	Motor oilers not upright on motors--oil lost
			Filters not installed
			No equipment labels
			Gap in ceiling mount allows air short-circuiting
			Sheetrock cut to gain access-fire wall violated
			Suspended ceiling grid blocks access opening
			Cabinet blocks shut-off valve handle
			Thermostat not as specified
			Aquastat installed on wrong piping
			Aquastat can not be located
		FPT	Fan runs too long after space temp satisfied
			Unit overheats vestibule

Discrepancies - Electrical Distribution and Miscellaneous Pumps

System	Sub-System	Test	Deficiency
Electrical Power	Grounding	Inspection	Ground not installed
Motors	Protection	Inspection	Safety heaters (fuses) are wrong size
	Controls	FPT	Two speed motors not wired for both speeds
			RAF motor trips when AHU VFD is in bypass
			Unused disconnect is mounted on AHU-no purpose

System	Sub-System	Test	Deficiency
Pumps	Sump Pump	FPT	Float switches improperly set to minimize cycles
	Sewage Injector	FPT	Pump making odd noises-debris in unit
			Control box full of debris
			Unit not securely mounted-shakes a lot
			Incorrect mounting elevation
	Well Pump	FPT	Pilot light inoperative
			Short cycle timer not set up

Discrepancies - Building Automation Systems

System	Sub-System	Test	Deficiency
EMCS	HVAC Sensors	Inspection	Sensor wires swapped between adjacent rooms
			No mapping to allow point to be monitored
			Wrong point address
			Wrong point label
			Poor water sensor location gives bad reading
			Wiring causes intermittent fault at panel
			Sensors inoperative
			Thermostat sensors insufficient range
			Set-point not programmed
			Incorrect sensor shown on control submittal
			Pump missing on control submittal
			Location senses mixed air instead of single air stream
			Freeze 'stat improperly supported-moves in airflow
			Only (1) filter DP sensor installed across pre-filter and final filter instead of (2) as shown on plans
			Leaking pneumatic lines to sensor causes bad readings
			Dirty filter switches not set
			Sensor installed with (1) out of (4) screws
			Supply/return sensors switched
			High/low pressure connections switched
			Freeze 'stat cold location results in false AHU lockout
		FPT	Lack of control of room temperature--poor sensor location
			Holes by static pressure sensor distort readings
			Sunlight distorts OSA temperature reading
			Pump diff. P. sensors w/not operate at low pump speeds
			Low hydronic pressure safety shutdown inoperative
			Temperature set-point adjust affects humidity setpoint
			Dx discharge air sensor in supply duct-rapid cycling
			Multiple boiler staging sensor in supply duct-cycling
			VAV box/duct pressure hunting
			Airflow switch chatters
	Actuators	FPT	Damper actuators not stroking fully
			Fume hood air valve not operating correctly
			Actuator stroke not calibrated correctly
			Control valve E/P transducers incorrectly calibrated
			Control valve direct operating instead of indirect
			Control air dryer not adjusted per manufacturer
	Occupancy Sensors	FPT	Sensors blocked by columns-lights go off
			Insufficient sensors for coverage-lights go off
	Operator Interface & Central	FPT	Parameters cannot be completely accessed
			No heating water temperature specified
			No cooling water temperature specified
			Control loop gain and other fine tuning not finished

Discrepancies - Building Automation Systems - *continued*

System	Sub-System	Test	Deficiency
	Operator Interface		Some alarms not programmed
	& Central		Trend log programming not complete
			Summary screen not completely implemented
			Outside air heating water lockout set too low
			OSA lockout not programmed
			Units incorrect on summary screen
			Cooling call at AHU will not activate chiller/pump
			Chilled water pressure inadequate at coil
			Relief damper opens in unoccupied recirc mode
			AHU trips on high pressure before duct static setpoint reached
			AHU doesn't go into full heating for morning startup
			AHU OSA damper doesn't open in morning purge mode
			Airflow measuring readout 20% greater than EMCS readout
			AHU listed in wrong building location
			Fume hoods listed in wrong building location
	Panels	Inspection	No permanent power to panels
			Controllers not connected to network
			Panel labels not installed
			Power supply transformer rest button is missing

Discrepancies - Fire Alarm Systems

Sub-System	Test	Deficiency
Pull Stations	Inspection	Clearance to insert reset key blocked by adjacent fire extinguisher
Annunciation	FPT	Horn/Strobe did not operate
		Water flow switch slow to alarm
Smoke dampers	Inspection	Ceiling hatch not fitting properly
		Duct inspection hatch inaccessible above suspended ceiling
		Mounting screws interfere with closing
		Elevator shaft smoke damper does not open
Automatic Door Closers	FPT	Wrong door of double doors closes first
		Closer out of adjustment
		Door not closing completely
Auto-Dialer	Inspection/FPT	Not installed
		Not programmed
Smoke Detectors	Inspection	Duct detectors not installed
		Detectors installed in mixed air stream instead of return flow
		Shuts down AHU in manual mode only
		Does not shut down AHU at all
General	FPT	NFPA 13 Required Inspections not complete
		Fire Marshall inspection form not submitted
		Spare sprinkler head holder obscured with writing

Discrepancies - Gauges and Package Generators

System	Sub-System	Test	Deficiency
Gauges	Thermometers	FPT	All thermometers in heating water system failed calibration check
	Flow meters	Inspection	Installation incomplete
			Meters not labeled
		FPT	Calibration not done
			Meter not connected to EMCS
			Meter reading inaccurate due to unfilled pipe(design)
	Condensate pump	Inspection	Gauge has wrong range
			Pressure gauge operates in vacuum--wrong scale

System	**Sub-System**	**Test**	**Deficiency**
Package Generator	General	Start-Up, Mechanical	Control panel connected to generator without vibration separation
			Anchor bolts insufficient in quality and quantity
			Generator frame bent
			Mufflers supports loose after operation
			No insulation on muffler and supports
		Start-up, Electrical	Wiring missing
		Start-up, controls	Gen. room EMCS panel not emergency powered
			Cooling dampers close on loss of regular power
			Generator room overheats
			Fault cannot be reset without wiring alteration
		Start-up, fuel	Fuel piping improperly supported
			Incorrect natural gas pressure setting
			Insufficient pressure for full load operation
			Gas piping leaking

Discrepancies - Hydronic Systems

System	Sub-System	Test	Deficiency
Hydronics, Heating	Piping	Flush/Clean	Leaks in drains, valves, joints
			Pipe hammer, pipes jumping up and down
			Only 10% glycol charge vrs. 30% required per plans
			Non-glycol system can freeze due to wall leaks
	Equipment	Inspection	Items not bolted down
			Items not seismically braced
			Strainers Missing
			Strainers Clogged
			Heating and cooling valves switched on drawings
			2-way cooling valve shown on dwgs as 3-way valve
			Valves installed on supply lines instead of return lines
			Balance valve ports obstructed by adjacent control valve actuator
			Large valve actuator is not supported in horizontal position
			Control valve hand operator missing
			Expansion charge to 16 psig vrs. 8 psig specified
			Make-up pressure regulator not adjusted properly
			Fast fill connection is not disconnected
			Coil vent valve not installed
			Coil test ports (Pete's Plugs) not installed
			Thermometer not installed
			Strainer on wrong side of balance valve
			Coil vent valve not shown on design drawing
			No flex connections from coil to piping
			No duct access for coil inspection
			No label on duct for coil location
			Coil supply/return reversed
			No fill connection to glycol feed tank
		FPT	Heating valve not closing (fail safe) on loss of power
			Valve wired to fail open instead of closed
			No manual control of coil control valve
			Boiler blowdown splatters out of floor drain and across room
			Boiler deaerator has severe water hammer
			Glycol feed tank pressure switch has incorrect range
			Heat transfer package missing expansion tank
			Residual boiler heat causes high temp trip on restart
	Pumps	FPT	Bad sensor location-control sequence not operating
			Controller will not alternate pumps as specified
Hydronics, Cooling	Equipment	Inspection	Relief valve blocks strainer access. Strainer clogged
			Future ground water filter location not marked as on drawings
		FPTs	Chiller locks out due to CHW warming during off periods
			Dx hot gas bypass is on third stage instead of first
Hydronics, Heat Recovery		Inspection	Fill funnel not installed
			Heat recovery sequence interferes with economizer cycle

Discrepancies - Lab Water, Gas, Steam

System	Sub-System	Test	Deficiency
Lab Water	Reverse Osmosis	Inspection	Design lacks backpressure valve to pressurize piping
	(RO)		Ph is running out of specification
			Design lacks pressure or water quality alarms
			Design lacks UV light malfunction alarm
			Tanks not supported
			Faucets labeled incorrectly
			Labels and tags missing
			Pressure test documents missing
			Hardness test kit not in RO room
			Bypass around prefilters can destroy membrane
			Pressure tank setting too low
			general alarm not mapped to EMCS
		FPT	Pump incorrect type-burned out
			Resistance sensor is wrong range
			TAB of RO not in TAB contract-need change order
			Need lockout of pump when tank is dry
Lab Gas	Bench supplies	Inspection	Pressure regulators not installed
			Labels and tags missing
			Pressure test documents missing
		FPT	Leaks in piping
			Insufficient pressure for some equipment

System	Sub-System	Test	Deficiency
Steam	Steam Traps	Inspection	Wrong type of trap
			Trap installed backwards
			Insufficient pressure rating
			Trap manufacturing defect
			Trap leaking steam by
	Control Valve	FPT	Design--Control valve too large--can't control temp
			1/3-2/3 valve sequence reversed
	Coils	Inspection	Vacuum breaker outlet blocked with insulation
	Relief Valve	Inspection	Valve not piped to floor as specified
	Boiler	FPT	Secondary fuel control will not enable start
			EMCS will not read boiler parameters from controller

Discrepancies - Plumbing Systems

System	Sub-System	Test	Deficiency
Drain, Waste & Vent	Trap Primers	Inspection	Trap primers shown on plans but not installed
			Trap primers not shown on plans
			Primers not flowing when taps turned on
			Multiple trap primer distributor missing
			Primer installation incomplete
	Floor Drains	Inspection	Floor Drain not installed
			Floor drain vent not tied to other vents
			Floor drain cleanout blocked by concrete
			Anchor bolts not installed
	Pressure regulator	FPT	Failed to maintain constant pressure under varying flow
	Expansion tank	FPT	Pre-charge pressure too low for city water pressure
	Potable water	Inspection	Disinfection and lab test forms not submitted
			Valves not labeled
	Toilets	FPT	Toilet not draining, trap arm pushed too far into tee
	Piping	Inspection	Future sink rough-in sewer pipe not plugged
			Rain water leaders not insulated
			Acid vent piping not extended through roof
Domestic Hot Water	Circulation	FPT	No circulation in a loop due to imbalance
			No balancing in hot water supply loops
	Piping/Equipment		Water heater drain pans fail and leak to floor below
			Hot water 120 to 130 dF. 110 dF is max allowable
			Tags and labels missing
			Maintenance lights out in plumbing chase
			Heater stm control valve too far from tank-overheats water
			Circulation temperature sensor is out of loop
			Expansion tank missing from design
Domestic Cold Water	Insulation	Inspection	Cold water insulation missing--condensation
			Insulation damaged/missing
	Fixtures	Inspection	Water fountain missing
			Clogged sink aerator
	Backflow prevention	Inspection	Drain not piped to floor
General		Inspection	City inspector certificate not submitted
			Equipment not labeled

Discrepancies - Test and Balance

System	Sub-System	Test	Deficiency
TAB	Hydronic	FPT	Total heating water flow only 75% of design
			Insufficient flow available at AHU control valve
			Pump flow adjusted with both lead/lag pumps on
			Pump balance incorrect due to unclear sequence of operation
			No flow through coil-plugged balance valve
	Air Side	FPT	Balance not performed with all zones in full cooling
			Balance not performed with grills installed
			Balance performed without fan sheave in place
			VFD used to balance fan flow instead of sheaves
			Dirty filters not accounted for in balancing
			(2) different test and balance reports in circulation
			Directional vanes not set on supply grills
			Programmed VAV max/min flows vary from design
	Fume Hoods	FPT	Fume hoods slow to come out of alarm (15 mins)
			Two-sided fume hood balanced with only (1) side opened

Discrepancies - VAV and other Terminal Units

System	Sub-System	Test	Deficiency
VAV Boxes		Inspection	Actuator mounting screws stripped and loose
			Control box covers missing
			No access above suspended ceiling
			Actuator linkage disconnected
			Box access panel sealed shut with duct sealant
			Insufficient straight duct into box for volume tracking
			Transition too close to box for volume tracking
			Box too high above suspended ceiling for maintenance
			Flex duct to box too long
			No earthquake bracing
			Actuator pneumatic tubing loose
VAV Boxes	Reheat Coil	FPT	Coil too small to heat area after night set-back
			Box cannot maintain room set-point
			Box too noisy--Minimum airflow too high
			Use of Occupancy sensors for heating makes room cold
			Coil leaking
			Filter not installed
	General	FPT	Incorrect deadband programmed
			Incorrect area factor in EMCS
			Diffuser CFM different than box CFM
Terminal Units	Reheat Coil	FPT	Excessive warm-up time due to undersized coil
			Units cannot maintain room set-point
			Air flow too high and drafty--Insufficient adjustment

Discrepancies - VFD *(Variable Frequency Drives)*

System	Test	Deficiency
VFD	Start-up	VFD burned out due to fan back-rotation (corrected by programming)
		VFD Overheated due to lack of cooling louvers
		Unnecessary line reactors installed
		Motor noise apparently caused by VFD
		VFD overloaded due to altitude (lack of cooling)
		Motor protection current incorrect
		VFD incorrectly programmed for auto-restart
		Motor maximum speed set above nameplate rating
		PID accel/decel/gain not set to minimize hunting
		Number of allowable restarts too high
		Number of motor poles not set at installation
	FPT	Different pumps operate at different speeds w/same signal
		Unexplained trips due to hot heat sink and load short circuit
		Incomplete programming
		Accel/decel time too short
		Tripping due to overloaded motor
		Tripping due to power quality